the history of technology

technology of the ancient world

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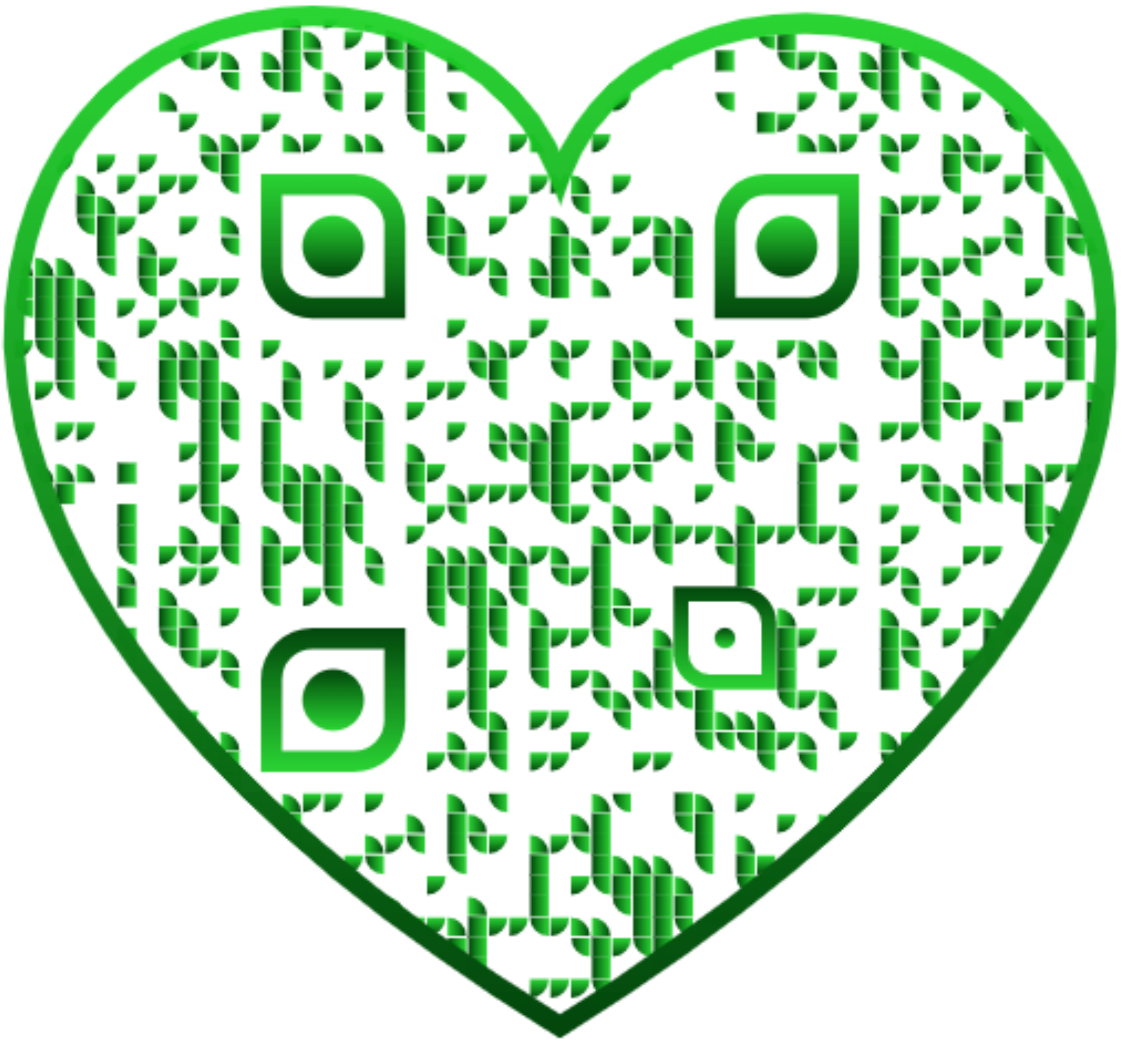

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The contemporary understanding of "technology" usually refers to advances in highly technical industries such as those related to computers, telecommunications, and the Internet. Modern technology is con- stantly evolving, with each new advance making older versions outmoded and eventu- ally obsolete. To understand the technology of the ancient world, as it is discussed in this book, the word must be thought of some- what differently. At its core, technology is the application of knowledge to manipulate one's environment and achieve a specific practical purpose. Working from this definition, many basic tools that people take for granted today were once revolutionary technologies.

The earliest technology was developed when human beings realized they could sharpen rocks and bones to improve their usability. This led to the creation of sim- ple tools, such as stone axes and arrow tips. Hunting became easier and meat more abun- dant, which naturally led to a need to preserve the game by cooking it. This need was met when humans learned to harness fire. Hunting provided food, and following game defined the lives and social structure of humans until they developed and refined the principles of agri- culture, transforming nomadic hunters into farmers. Two-wheeled carts were invented in

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Each advance in technology led to further technological needs. Effective farming and transportation allowed for a denser popula- tion, and after about 3500 BCE cities began to grow. The Stone Age was followed by the Bronze Age in about 3000 BCE when humans discovered that copper, repeatedly hammered and put into a fire, would not crack, which preceded the discovery that alloys of tin and copper produced a strong and malleable bronze that could be used for swords and sick- les. Mining, metalworking, and trade brought wealth to the newly formed cities and with it a change in the social structure. Armies were needed to defend and sometimes conquer new home territories. Construction of fortifica- tions, public structures, waterworks, and dams formed the beginnings of engineering.

This book examines the technology of the ancient world from the foundational advances of Stone Age hominids to the mastery of iron work and the construction of aqueducts in ancient Greece and Rome. It studies tech- nologies developed for military defense and supremacy, as well as those related to the pro- duction of food from Europe to the Indian subcontinent. It also considers the leaps in technological innovation accompanying the change from a widespread population to tightly settled urban centers.

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Chapter

STONE AGE TECHNOLOGY

The identification of the history of technology with the history of humanlike species does not help in fixing a precise point for its origin because the estimates of prehis- torians and anthropologists concerning the emergence of human species vary so widely. Animals occasionally use natural tools such as sticks or stones, and the ancestors of humans doubtless did the same for hundreds of mil- lennia before the first giant step of fashioning their own tools. Even then it was an intermi- nable time before they put such toolmaking on a regular basis, and still more aeons passed as they arrived at the successive stages of stan- dardizing their simple stone choppers and pounders and of manufacturing them—that is, providing sites and assigning specialists to the work. A degree of specialization in toolmaking

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was achieved by the time of the Neanderthals (70,000 BCE); more-advanced tools, requiring assemblage of head and haft, were produced by Cro-Magnons (perhaps as early as 35,000 BCE); while the application of mechanical principles was achieved by pottery-making Neolithic (New Stone Age; 6000 BCE) and Metal Age peoples (about 3000 BCE).

EARLIEST COMMUNITIES

For all except approximately the past 10,000 years, humans lived almost entirely in small nomadic communities dependent for survival on their skills in gathering food, hunting and fishing, and avoiding predators. It is reasonable to suppose that most of these communities developed in tropical latitudes, especially in Africa, where climatic conditions are most favourable to a creature with such poor bodily protection as humans have. It is also reason- able to suppose that tribes moved out thence into the subtropical regions and eventually into the landmass of Eurasia, although their coloni-zation of this region must have been severely limited by the successive periods of glaciation, which rendered large parts of it inhospitable and even uninhabitable, even though human- kind has shown remarkable versatility in adapting to such unfavorable conditions.

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THE NEOLITHIC REVOLUTION

Toward the end of the last ice age, some 15,000 to 20,000 years ago, a few of the communities that were most favoured by geography and cli- mate began to make the transition from the long period of Paleolithic, or Old Stone Age, savagery to a more settled way of life depend- ing on animal husbandry and agriculture. This period of transition, the Neolithic Period, or New Stone Age, led eventually to a marked rise in population, to a growth in the size of com- munities, and to the beginnings of town life. It is sometimes referred to as the Neolithic Revolution because the speed of technological innovation increased so greatly and human social and political organization underwent a corresponding increase in complexity. To understand the beginnings of technology, it is thus necessary to survey developments from the Old Stone Age through the New Stone Age down to the emergence of the first urban civili- zations about 3000 BCE.

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stone. Though it may be assumed that primi- tive humans used other materials such as wood, bone, fur, leaves, and grasses before they mastered the use of stone, apart from bone antlers, presumably used as picks in flint mines and elsewhere, and other fragments of bone implements, none of these has survived. The stone tools of early humans, on the other hand, have survived in surprising abundance, and over the many millennia of prehistory important advances in technique were made in the use of stone. Stones became tools only when they were shaped deliberately for specific purposes, and, for this to be done efficiently, suitable hard and fine-grained stones had to be found and means devised for shaping them and particularly for putting a cutting edge on them. Flint became a very popular stone for this purpose, although fine sandstones and certain volcanic rocks were also widely used. There is much Paleolithic evidence of skill in flaking and polishing stones to make scraping and cutting tools. These early tools were held in the hand, but gradually ways of protecting the hand from sharp edges on the stone, at first by wrapping one end in fur or grass or setting it in a wooden handle, were devised. Much later the technique of fixing the stone head to a haft converted these hand tools into more versatile tools and weapons.

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With the widening mastery of the mate- rial world in the Neolithic Period, other substances were brought into service, such as clay for pottery and brick, and increasing competence in handling textile raw materials led to the creation of the first woven fabrics to take the place of animal skins. About the same time, curiosity about the behavior of metallic oxides in the presence of fire promoted one of the most significant technological innovations of all time and marked the succession from the Stone Age to the Metal Age.

Power

The use of fire was another basic technique mastered at some unknown time in the Old Stone Age. The discovery that fire could be tamed and controlled and the further discov- ery that a fire could be generated by persistent friction between two dry wooden surfaces were momentous. Fire was the most impor- tant contribution of prehistory to power technology, although little power was obtained directly from fire except as defense against wild animals. For the most part, prehistoric communities remained completely dependent upon manpower, but, in making the transition to a more settled pattern of life in the New Stone Age, they began to derive some power

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from animals that had been domesticated. It also seems likely that by the end of prehistoric times the sail had emerged as a means of har- nessing the wind for small boats, beginning a long sequence of developments in marine transport.

Tools and Weapons

The basic tools of prehistoric peoples were determined by the materials at their disposal. But once they had acquired the techniques of working stone, they were resourceful in devis- ing tools and weapons with points and barbs. Thus, the stone-headed spear, the harpoon, and the arrow all came into widespread use. The spear was given increased impetus by the spear- thrower, a notched pole that gave a sling effect. The bow and arrow were an even more effective combination, the use of which is clearly demonstrated in the earliest "documen- tary" evidence in the history of technology, the cave paintings of southern France and north- ern Spain, which depict the bow being used in hunting. The ingenuity of these primitive hunters is also shown in their slings, throwing- sticks (the boomerang of the Australian Aborigines is a remarkable surviving example), blowguns, bird snares, fish and animal traps, and nets. These tools did not evolve uniformly,

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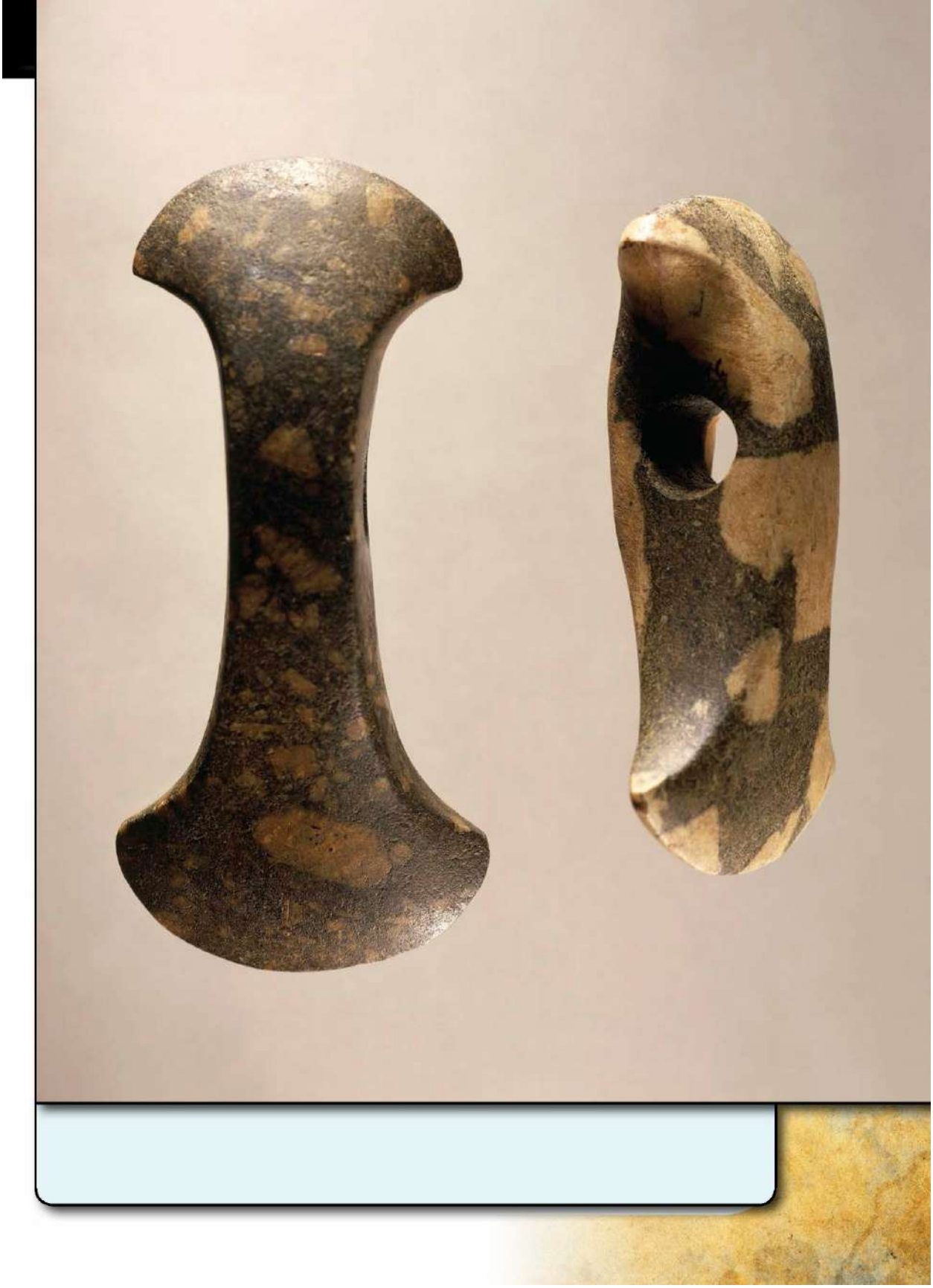
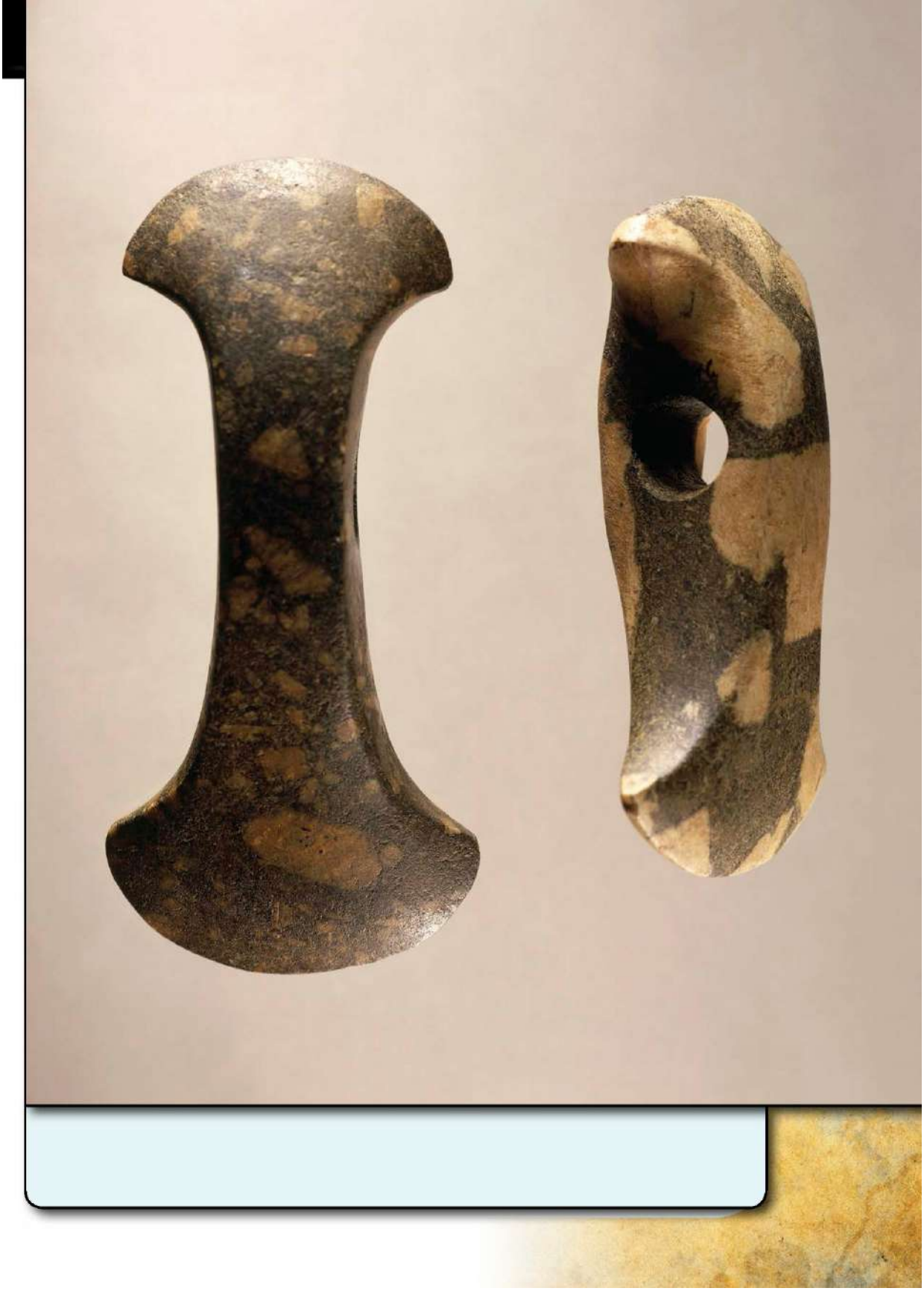


Examples of Neolithic axes from Sweden



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as each primitive community developed only those instruments that were most suitable for its own specialized purposes, but all were in use by the end of the Stone Age. In addition, the Neolithic Revolution had contributed some important new tools that were not primarily concerned with hunting. These were the first mechanical applications of rotary action in the shape of the potter's wheel, the bow drill, the pole lathe, and the wheel itself. It is not possible to be sure when these significant devices were invented, but their presence in the early urban civilizations suggests some continuity with the late Neolithic Period. The potter's wheel, driven by kicks from the operator, and the wheels of early vehicles both gave continu- ous rotary movement in one direction. The drill and the lathe, on the other hand, were derived from the bow and had the effect of spinning the drill piece or the workpiece first in one direction and then in the other.

Developments in food production brought further refinements in tools. The processes of food production in Paleolithic times were simple, consisting of gathering, hunting, and fishing. If these methods proved inadequate to sustain a community, it moved to better hunting grounds or perished. With the onset of the Neolithic Revolution, new food-producing

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Building Techniques

Prehistoric building techniques also under- went significant developments in the Neolithic Revolution. Nothing is known of the building ability of Paleolithic peoples beyond what can be inferred from a few fragments of stone shel- ters, but in the New Stone Age some impressive structures were erected, primarily tombs and burial mounds and other religious edifices, but also, toward the end of the period, domestic housing in which sun-dried brick was first used. In northern Europe, where the Neolithic transformation began later than around the eastern Mediterranean and lasted longer, huge stone monuments, of which Stonehenge in England is the outstanding example, still bear eloquent testimony to the technical skill, not

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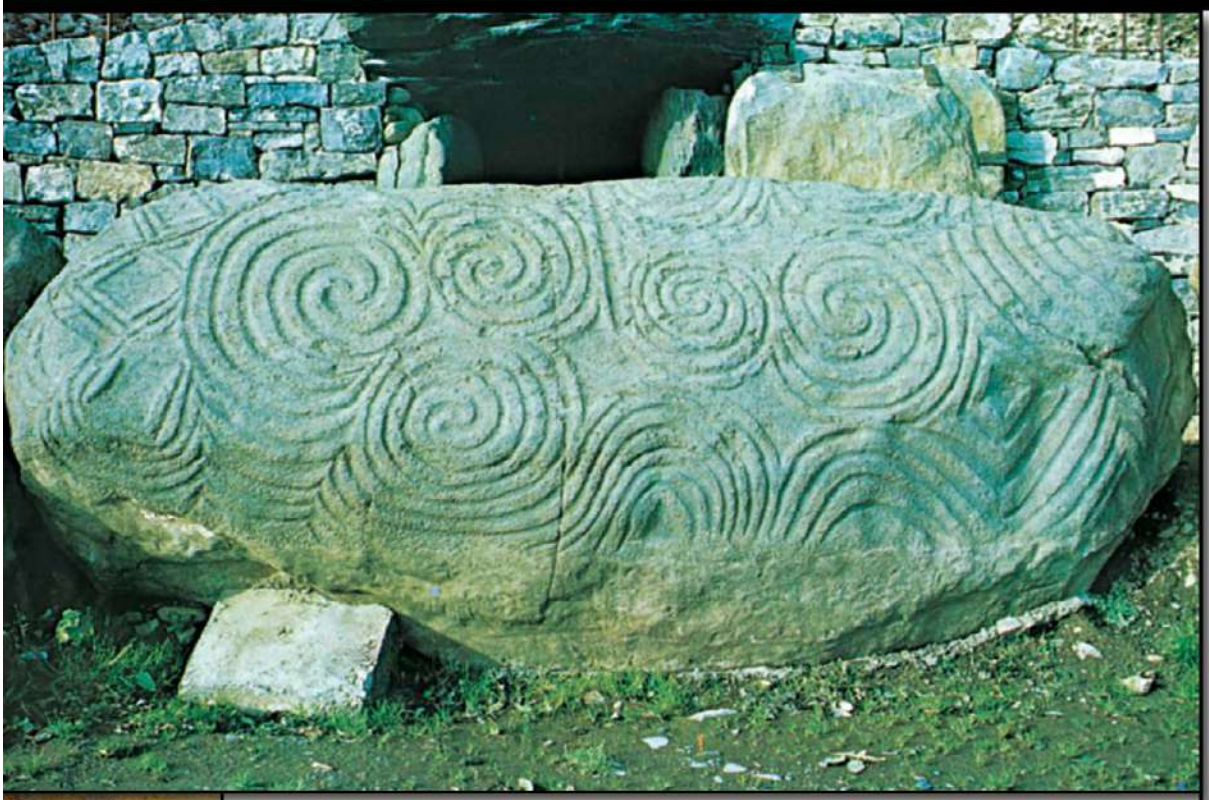

Entrance stone to a tomb, County Meath, Ireland c. 3200 BC

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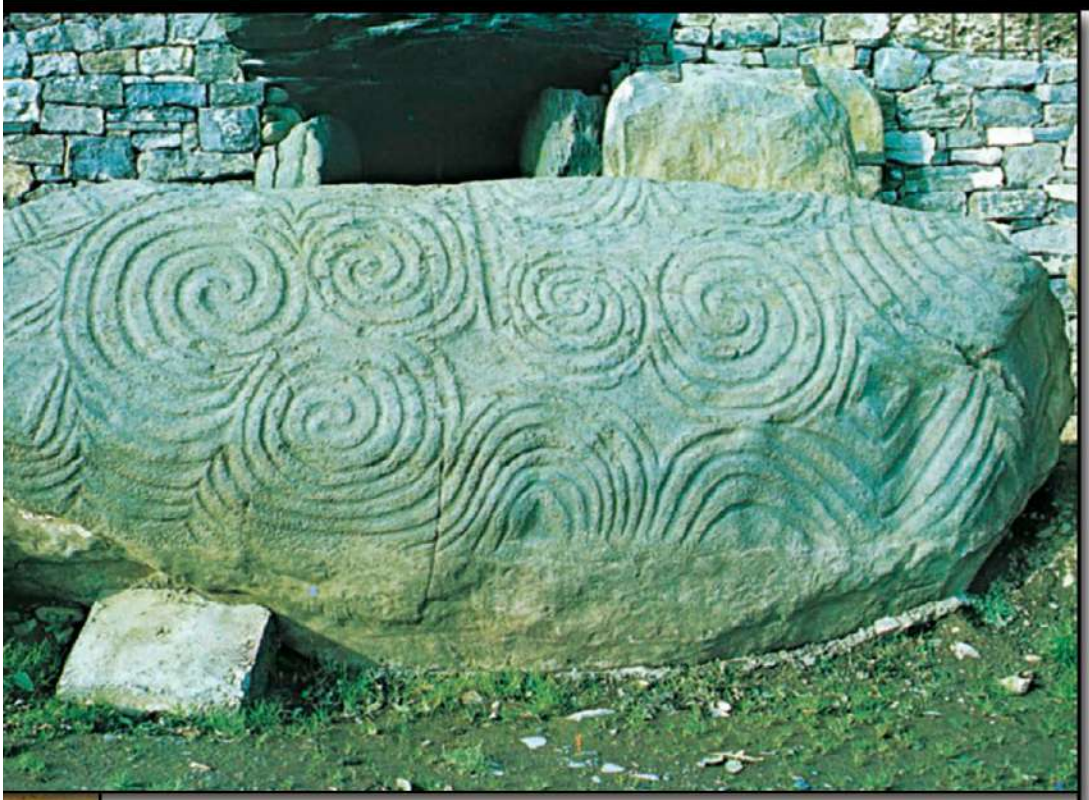
Manufacturing

The manufacturing industry had its origin in the New Stone Age, with the application of techniques for grinding corn, baking clay, spinning and weaving textiles, and also, it seems likely, for dyeing, fermenting, and distilling. Some evidence for all these processes can be derived from archaeological findings, and



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some of them at least were developing into specialized crafts by the time the first urban civilizations appeared. In the same way, the early metalworkers were beginning to acquire the techniques of extracting and working the softer metals, gold, silver, copper, and tin, that were to make their successors a select class of craftsmen. All these incipient fields of special- ization, moreover, implied developing trade between different communities and regions, and again the archaeological evidence of the transfer of manufactured products in the later Stone Age is impressive. Flint arrowheads of particular types, for example, can be found widely dispersed over Europe, and the impli- cation of a common locus of manufacture for each is strong.

Such transmission suggests improving facilities for transport and communication. Paleolithic people presumably depended entirely on their own feet, and this remained the normal mode of transport throughout the Stone Age. Domestication of the ox, the don- key, and the camel undoubtedly brought some help, although difficulties in harnessing the horselongdelayedits effective use. The dugout canoe and the birch-bark canoe demonstrated the potential of water transport, and, again, there is some evidence that the sail had already appeared by the end of the New Stone Age.

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It is notable that the developments so far described in human prehistory took place over a long period of time, compared with the 5,000 years of recorded history, and that they took place first in very small areas of the Earth's surface and involved populations minute by modern criteria. The Neolithic Revolution occurred first in those parts of the world with an unusual combination of quali- ties: a warm climate, encouraging rapid crop growth, and an annual cycle of flooding that naturally regenerated the fertility of the land. On the Eurasian-African landmass such con- ditions occur only in Egypt, Mesopotamia, northern India, and some of the great river valleys of China. It was there, then, that men and women of the New Stone Age were stim- ulated to develop and apply new techniques of agriculture, animal husbandry, irrigation, and manufacture, and it was there that their enterprise was rewarded by increasing pro- ductivity, which encouraged the growth of population and triggered a succession of socio- political changes that converted the settled Neolithic communities into the first civiliza- tions. Elsewhere the stimulus to technological innovation was lacking or was unrewarded so that those areas had to await the transmission of technical expertise from the more highly favoured areas. Herein is rooted the separation

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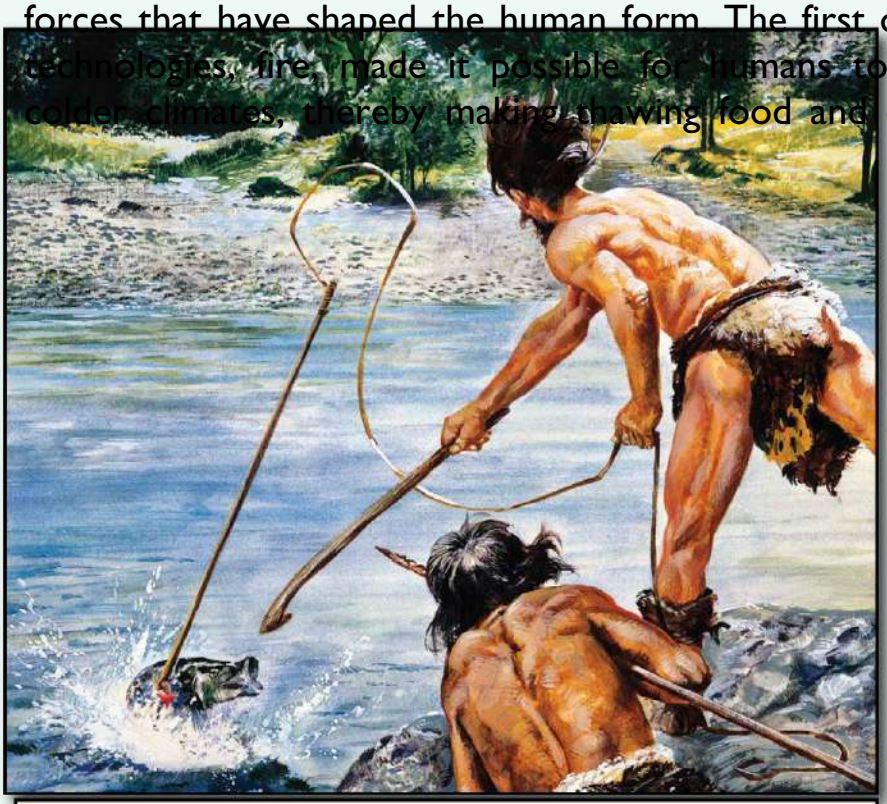

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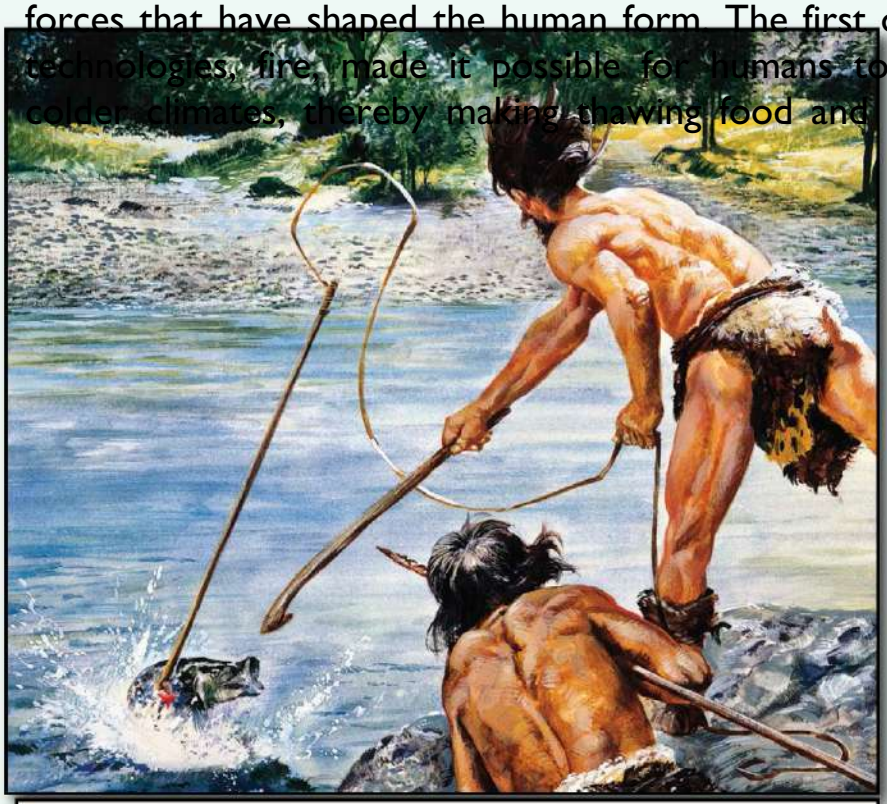

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and particularly the soft metals, such as gold and copper, which could be fashioned by beat- ing. Then came the discovery of the possibility of extracting certain metals from the ores in which they generally occur. Probably the first such material to be used was the carbonate of copper known as malachite, then already in use as a cosmetic and easily reduced to copper in a strong fire. It is impossible to be precise about the time and place of this discovery, but its consequences were tremendous. It led to the search for other metallic ores, to the devel- opment of metallurgy, to the encouragement of trade in order to secure specific metals, and to the further development of specialist skills. It contributed substantially to the emergence of urban societies, as it relied heavily upon trade and manufacturing industries, and thus to the rise of the first civilizations. The Stone Age gave way to the early Metal Age, and a new epoch in the story of humankind had begun.

By fairly general consent, civilization consists of a large society with a common culture, settled communities, and sophisticated institutions, all of which presuppose a mastery of elementary literacy and numeration. Mastery of the civilized arts was a minority pursuit in the early civilizations, in all probability the carefully guarded possession of a priestly caste. The very existence of these skills, however,

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Hitherto, technology had existed without the benefit of science, but, by the time of the first Sumerian astronomers, who plotted the motion of the heavenly bodies with remark- able accuracy and based calculations about the calendar and irrigation systems upon their observations, the possibility of a creative relationship between science and technology had appeared. The first fruits of this relationship appeared in greatly improved abilities to measure land, weigh, and keep time, all practical techniques, essential to any complex society, and inconceivable without literacy and the beginnings of scientific observation. With the emergence of these skills in the 3rd millennium BCE, the first civilizations arose in the valleys of the Nile and of the Tigris-Euphrates.

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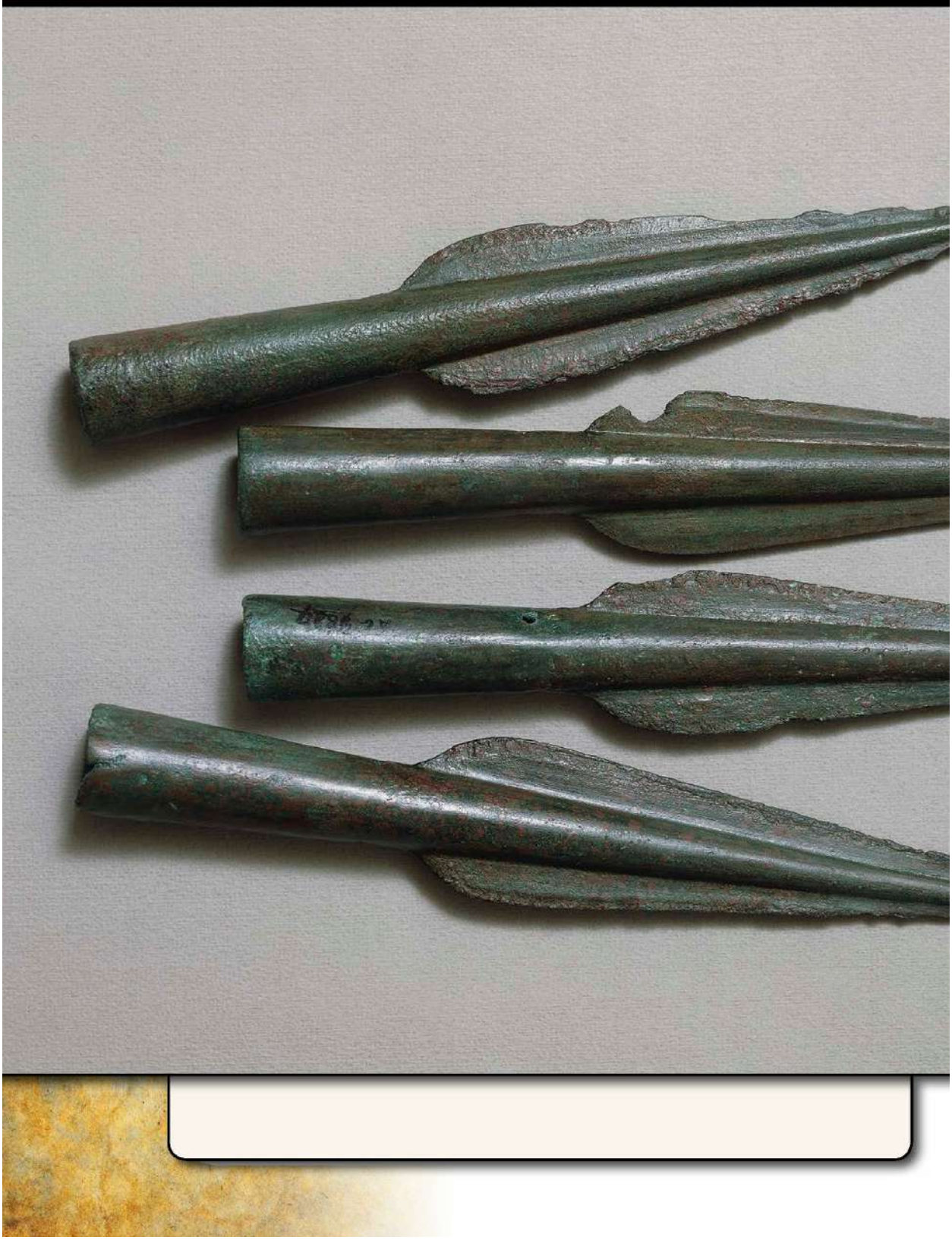

Bronze Age spearheads from Canatello, Italy

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Bronze became the most important mate- rial of the early civilizations, and elaborate arrangements were made to ensure a continu- ous supply of it. Metals were scarce in the alluvial river valleys where civilization devel- oped and therefore had to be imported. This need led to complicated trading relationships and mining operations at great distances from the homeland. Tin presented a particu- larly severe problem, as it was in short supply throughout the Middle East. The Bronze Age civilizations were compelled to search far beyond their own frontiers for sources of the metal, and in the process knowledge of the civ- ilized arts was gradually transmitted westward along the developing Mediterranean trade routes.

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In most aspects other than the use of metals, the transition from the technology of the New Stone Age to that of early civilizations was fairly gradual, although there was a gen- eral increase in competence as specialized skills became more clearly defined, and in techniques of building there were enormous increases in the scale of enterprises. There were no great innovations in power technol- ogy, but important improvements were made in the construction of furnaces and kilns in response to the requirements of the metal- workers and potters and of new artisans such as glassworkers. Also, the sailing ship assumed a definitive shape, progressing from a vessel with a small sail rigged in its bows and suit- able only for sailing before the prevailing wind up the Nile River, into the substantial ocean- going ship of the later Egyptian dynasties, with a large rectangular sail rigged amidships. Egyptian and Phoenician ships of this type could sail before the wind and across the wind, but for making headway into the wind they had to resort to manpower. Nevertheless, they accomplished remarkable feats of navigation, sailing the length of the Mediterranean and even passing through the Pillars of Hercules into the Atlantic.

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THE LOST-WAX PROCESS

The lost-wax process, also called cire-perdue, is a method of metal casting in which a molten metal is poured into a mold that has been created by means of a wax model. Once the mold is made, the wax model is melted and drained away. A hollow core can be effected by the introduction of a heat-proof core that prevents the molten metal from totally filling the mold. Common on every continent except Australia, the lost-wax method dates from the 3rd millennium BCE and has sustained few changes since then.

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To cast a clay model in bronze, a mold is made from th model, and the inside of this negative mold is brushed wit melted wax to the desired thickness of the final bronze. Afte removal of the mold, the resultant wax shell is filled with heat-resistant mixture. Wax tubes, which provide ducts fo pouring bronze during casting and vents for the noxious gase produced in the process, are fitted to the outside of the wa shell, which may be modeled or adjusted by the artist. Met pins are hammered through the shell into the core to secure Next, the prepared wax shell is completely covered in layer of heat-resistant plaster, and the whole is inverted and place in an oven. During heating, the plaster dries and the wa runs out through the ducts created by the wax tubes. Th plaster mold is then packed in sand, and molten bronze poured through the ducts, filling the space left by the wax When cool, the outer plaster and core are removed, and th bronze may receive finishing touches.

IRRIGATION

Techniques of food production also showed many improvements over Neolithic meth- ods, including one outstanding innovation in the shape of systematic irrigation. The civili- zations of Egypt and Mesopotamia depended heavily upon the two great river systems, the Nile and the Tigris-Euphrates, which both watered the ground with their annual floods and rejuvenated it with the rich alluvium they deposited. The Nile flooded with regularity each summer, and the civilizations building in

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The manufacturing industry in the early civilizations concentrated on such products as pottery, wines, oils, and cosmetics, which had begun to circulate along the incipient trade routes before the introduction of metals; these became the commodities traded for the metals. In pottery, the potter's wheel became widely used for spinning the clay into the desired shape, but the older technique of building pots by hand from rolls of clay remained in use for some purposes. In the production of wines and oils various forms of press were developed,

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Pack animals were still the primary means of land transport, the wheeled vehicle devel- oping slowly to meet the divergent needs of agriculture, trade, and war. In the latter category, the chariot appeared as a weapon, even though its use was limited by the continuing difficulty of harnessing a horse. Military technology brought the development of metal plates for armor.

BUILDING

In building technology the major develop- ments concerned the scale of operations rather than any particular innovation. The late Stone Age communities of Mesopotamia had already built extensively in sun-dried brick. Their suc- cessors continued the technique but extended its scale to construct the massive square temples called ziggurats. These had a core and facing of bricks, the facing walls sloping slightly inward and broken by regular pilasters built into the brickwork, the whole structure ascending in two or three stages to a temple on the summit. Sumerians were also the first to build columns with brick made from local clay,

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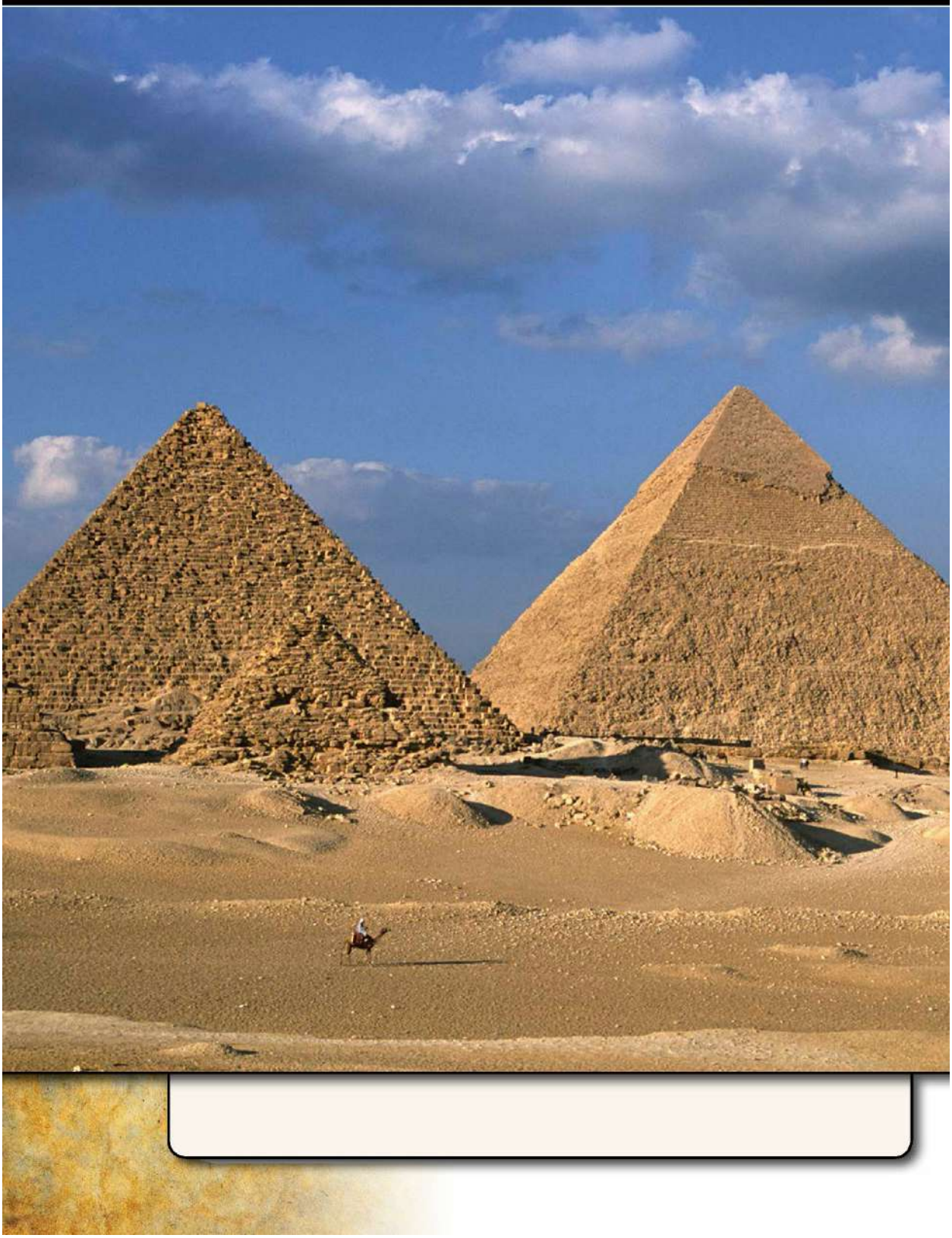
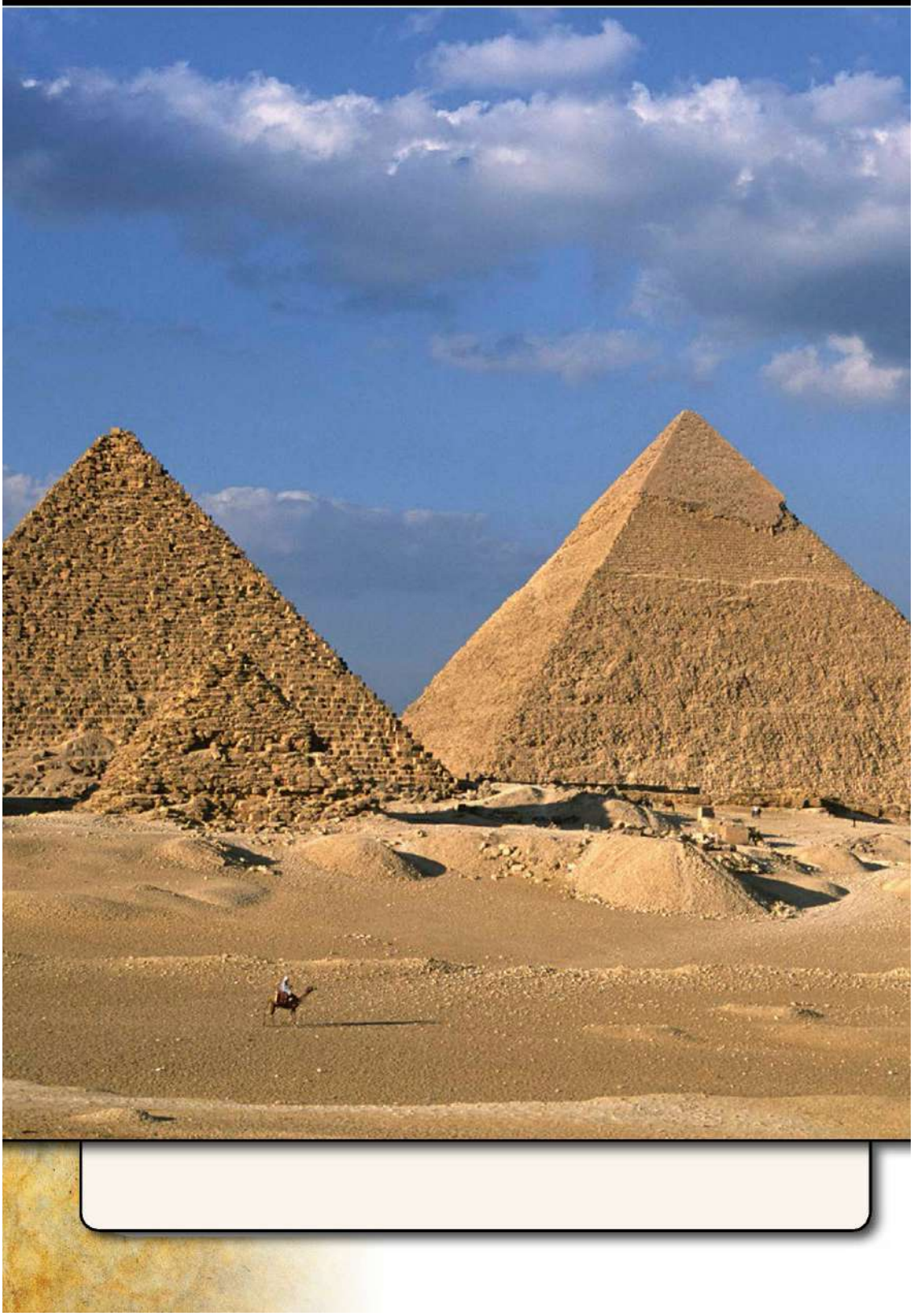


The pyramids at Giza, Egypt



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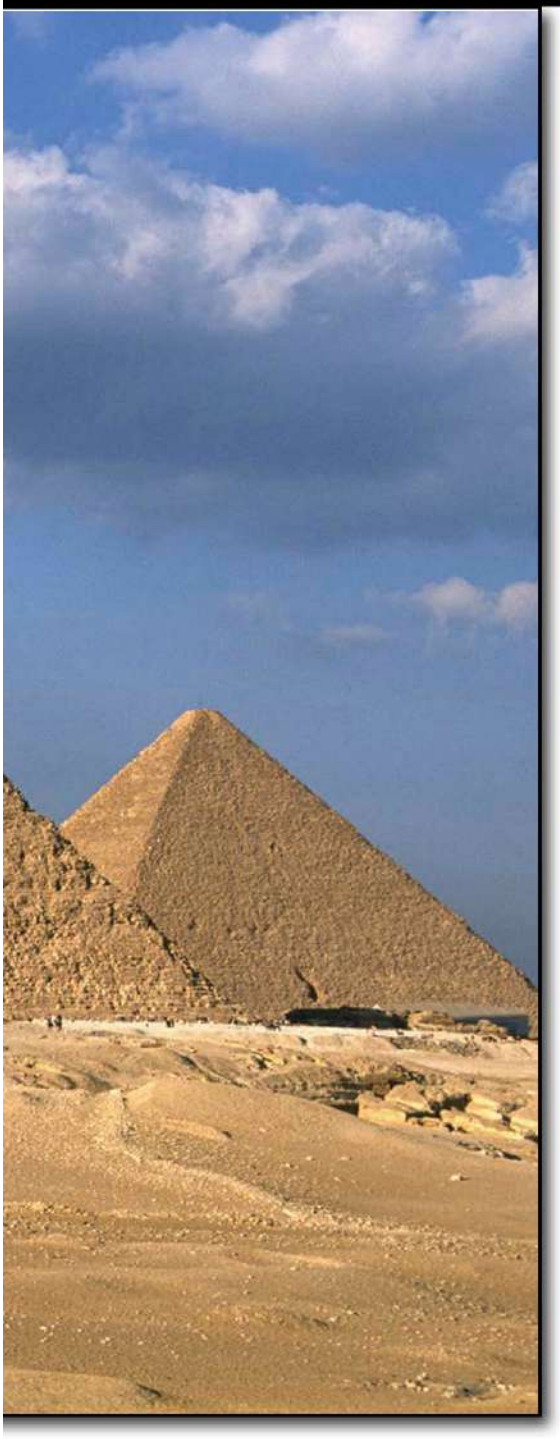
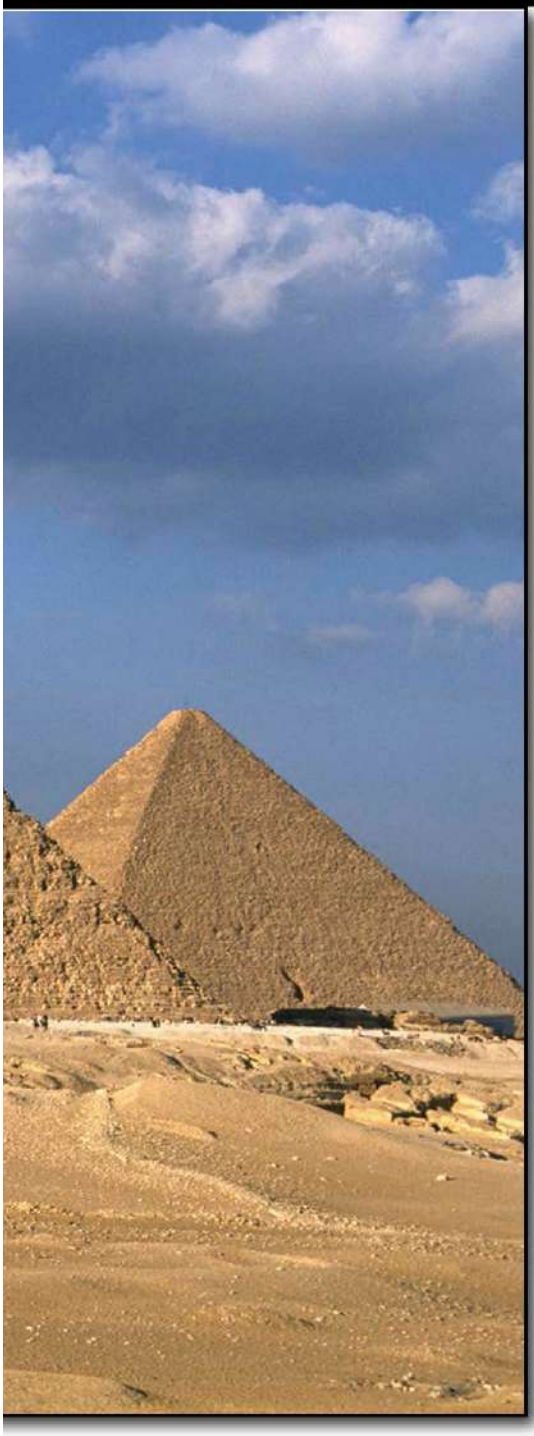


which also provided the writing material for the scribes.

In Egypt, clay was scarce but good building stone was plentiful, and builders used it in constructing the pyramids and temples that remain today as outstanding monuments of Egyptian civilization. Stones were pulled on rollers and raised up the successive stages of the structure by ramps and by bal- anced levers adapted from the water-raising shadoof. The stones were shaped by skilled masons, and they were placed in position under the careful supervi- sion of priest-architects who were clearly com- petent mathematicians and astronomers, as is evident from the precise astronomical



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alignments. It seems certain that the heavy labor of construction fell upon armies of slaves, which helps to explain both the achievements and limitations of early civilizations. Slaves were usually one of the fruits of military con- quest, which presupposes a period of successful territorial expansion, although their status as a subject race could be perpetuated indefinitely. Slave populations provided a competent and cheap labor force for the major constructional works that have been described. On the other hand, the availability of slave labor discour- aged technological innovation, a social fact that goes far toward explaining the compara- tive stagnation of mechanical invention in the ancient world.

TRANSMITTING KNOWLEDGE

In the ancient world, technological knowl- edge was transmitted by traders, who went out in search of tin and other commodities, and by craftsmen in metal, stone, leather, and the other mediums, who passed their skills to others by direct instruction or by providing models that challenged other craftsmen to copy them. This transmission through inter- mediary contact was occurring between the

alignments. It seems certain that the heavy labor of construction fell upon armies of slaves, which helps to explain both the achievements and limitations of early civilizations. Slaves were usually one of the fruits of military con- quest, which presupposes a period of successful territorial expansion, although their status as a subject race could be perpetuated indefinitely. Slave populations provided a competent and cheap labor force for the major constructional works that have been described. On the other hand, the availability of slave labor discour- aged technological innovation, a social fact that goes far toward explaining the compara- tive stagnation of mechanical invention in the ancient world.

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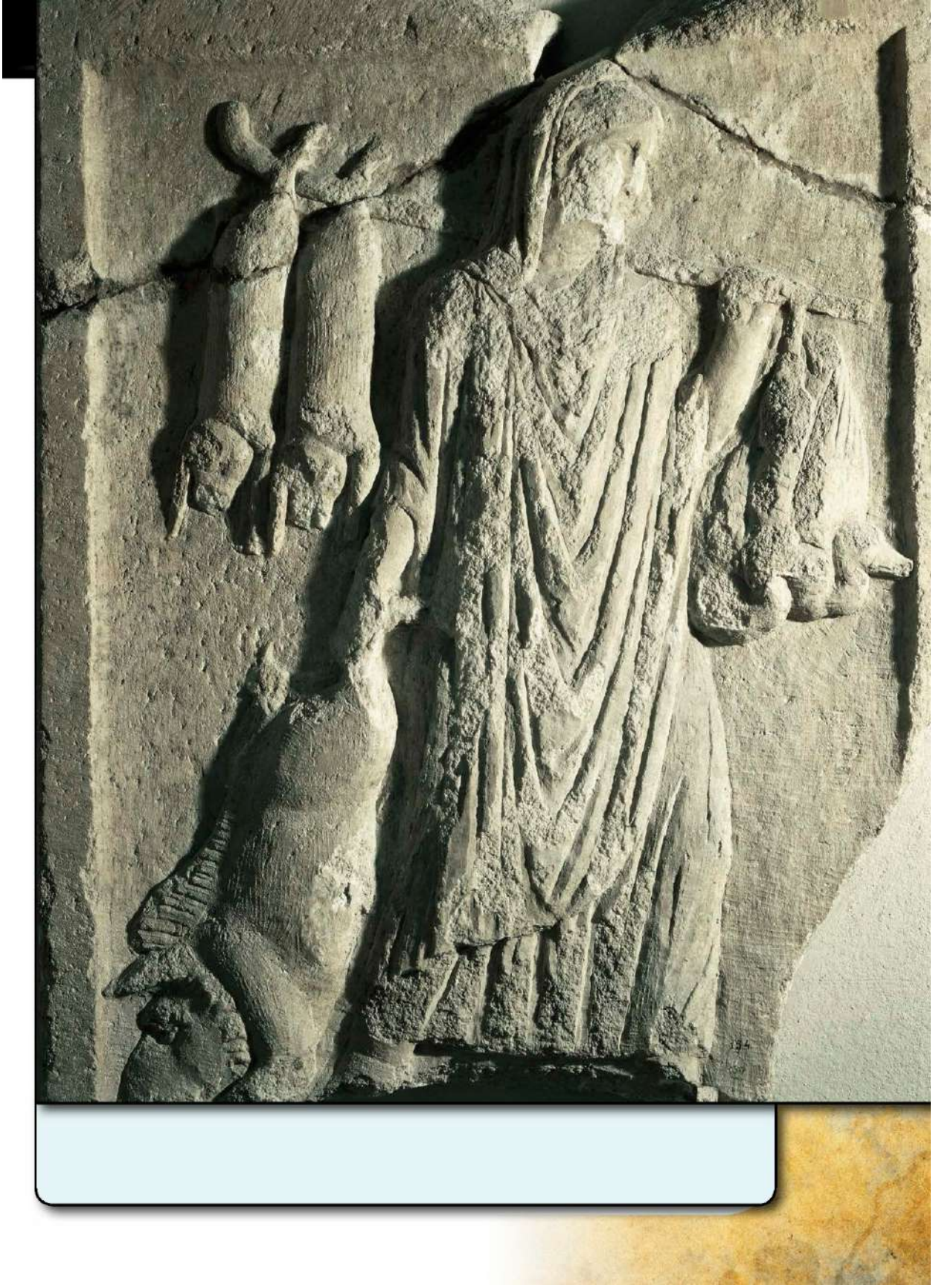

Detail of a wild game trader, 5th century BCE

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ancient civilizations and their neighbors to the north and west during the 2nd millennium BCE. The pace quickened in the subsequent millennium, distinct new civilizations arising in Crete and Mycenae, in Troy and Carthage. Finally, the introduction of the technique of working iron profoundly changed the capabilities and resources of human societies and ushered in the Classical civilizations of Greece and Rome.

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TECHNOLOGICAL ACHIEVEMENTS OF GREECE AND ROME

The contributions of Greece and Rome in philosophy and religion, political and legal institutions, poetry and drama, and in the realm of scientific speculation stand in spec- tacular contrast with their relatively limited contributions in technology. Their mechani- cal innovation was not distinguished, and, even in the realms of military and construc- tion engineering, in which they showed great ingenuity and aesthetic sensibility, their work represented more a consummation of earlier lines of development than a dramatic innova- tion. This apparent paradox of the Classical period of the ancient world requires explana- tion, and the history of technology can provide some clues to the solution of the problem.

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THE MASTERY OF IRON

The outstanding technological factor of the Greco-Roman world was the smelting of iron, a technique—derived from unknown metallurgists, probably in Asia Minor, about 1000 BCE—that spread far beyond the provincial frontiers of the Roman Empire. The use of the metal had become general in Greece and the Aegean Islands by the dawn of the Classical period about 500 BCE, and it appears to have spread quickly westward thereafter. Iron ore, long a familiar mate- rial, had defied reduction into metallic form because of the great heat required in the furnace to perform the chemical transforma- tion (about 1,535 °C [2,795 °F] compared with the 1,083 °C [1,981 °F] necessary for the reduction of copper ores). To

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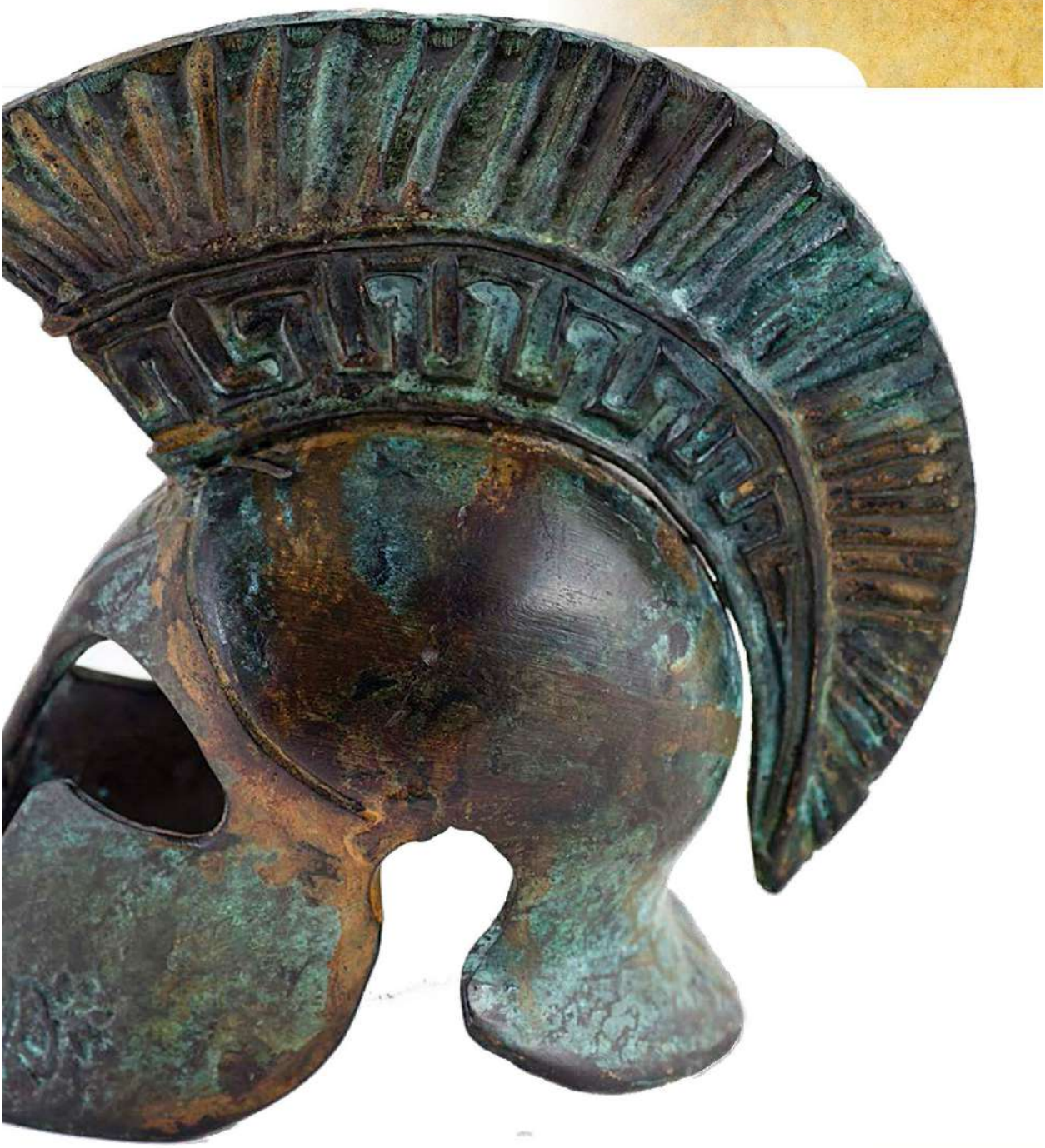
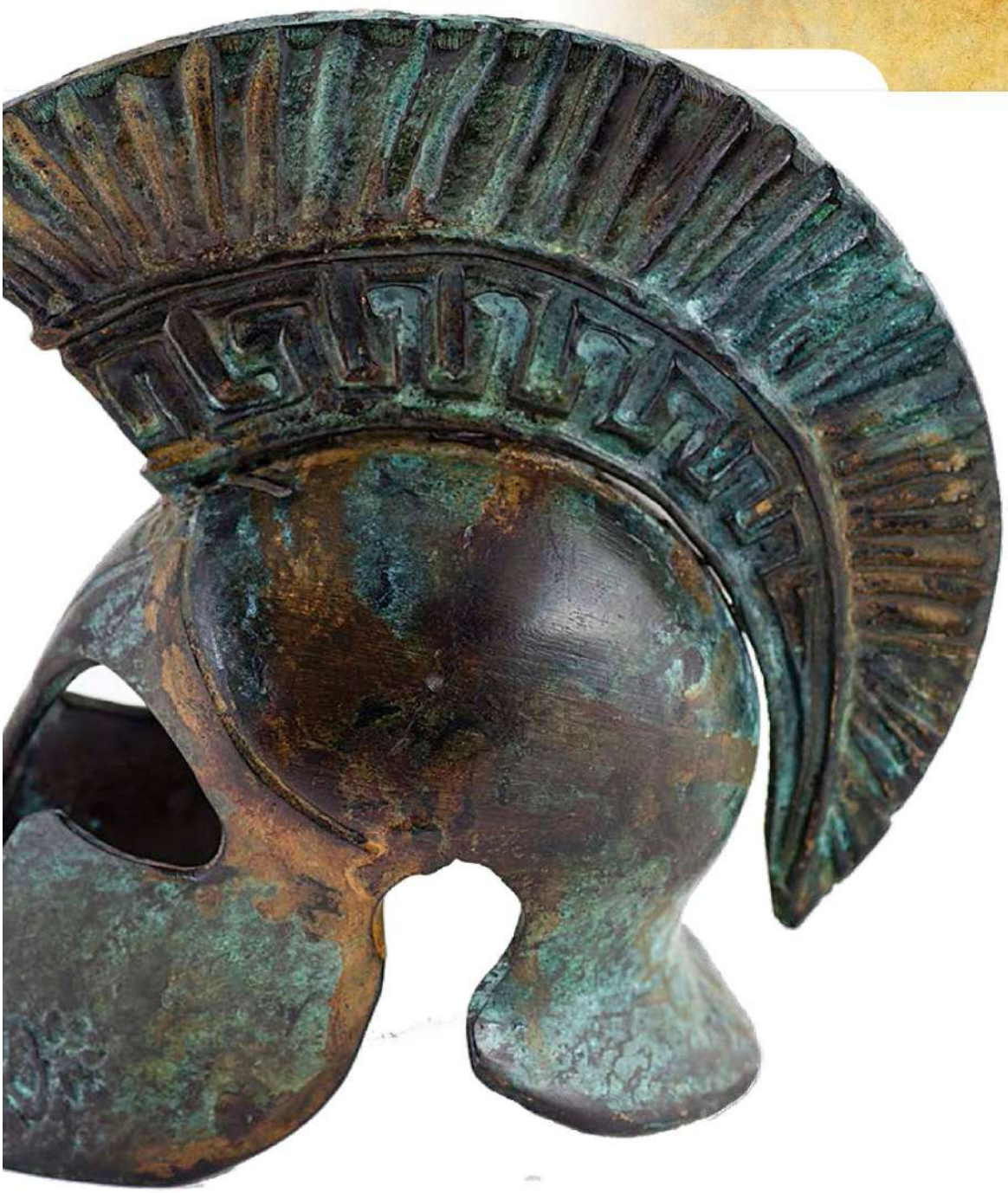


An example of a Trojan helmet



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reach this temperature, furnace construction had to be improved and ways devised to main- tain the heat for several hours. Throughout the Classical period these conditions were achieved only on a small scale, in furnaces burning charcoal and using foot bellows to intensify the heat, and even in these furnaces the heat was not sufficient to reduce the ore completely to molten metal. Instead, a small spongy ball of iron —called a bloom—was pro- duced in the bottom of the furnace. This was extracted by breaking open the furnace, and then it was hammered into bars of wrought iron, which could be shaped as required by fur- ther heating and hammering. Apart from its greater abundance, iron for most purposes pro- vided a harder and stronger material than the earlier metals, although the impossibility of casting it into molds like bronze was an incon- venience. At an early date some smiths devised the cementation process for reheating bars of iron between layers of charcoal to carburize the surface of the iron and thus to produce a coat of steel. Such case-hardened iron could be further heated, hammered, and tempered to make knife and sword blades of high qual- ity. The very best steel in Roman times was Seric steel, brought into the Western world from India, where it was produced in blocks a few inches in diameter by a crucible process,

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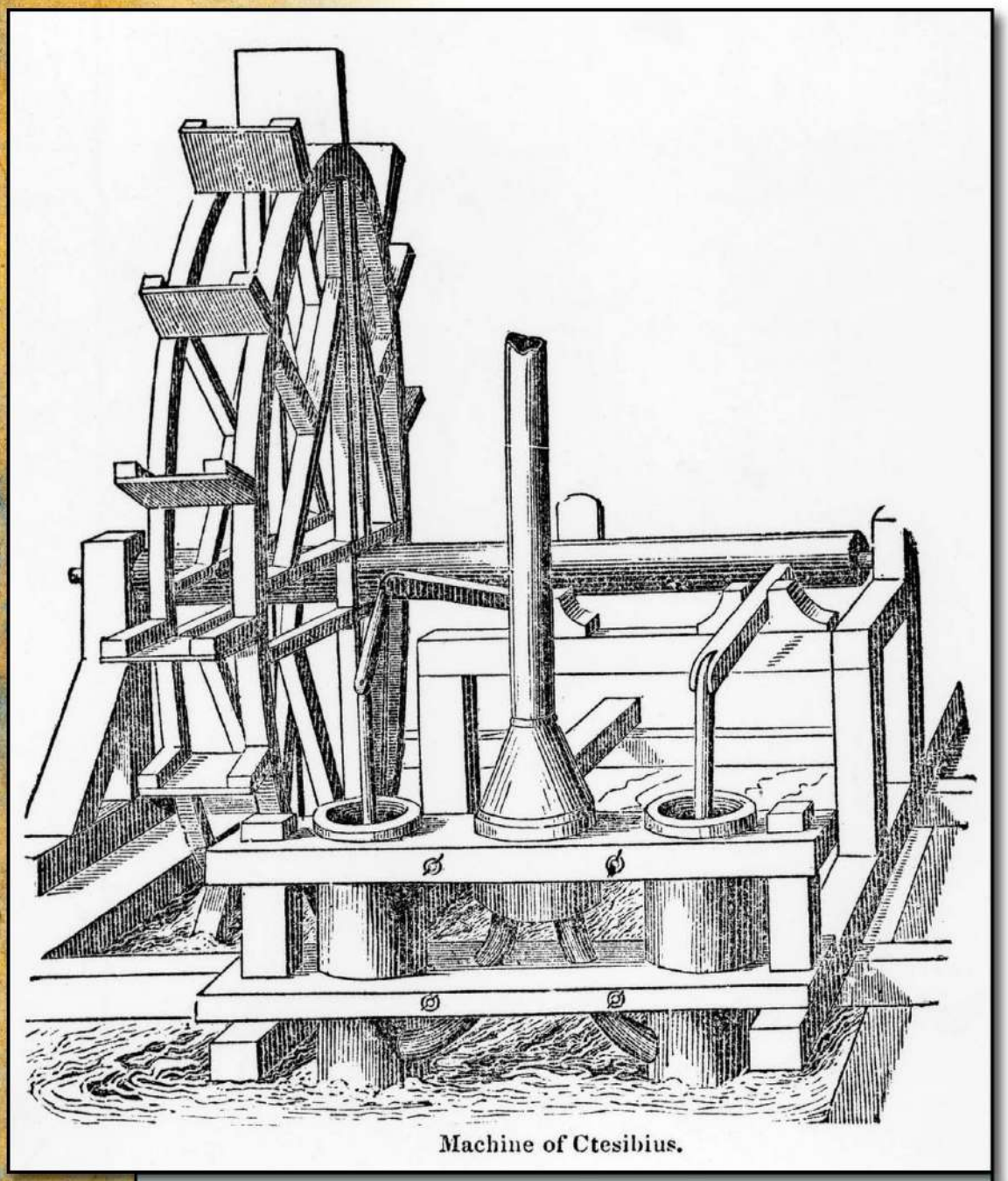
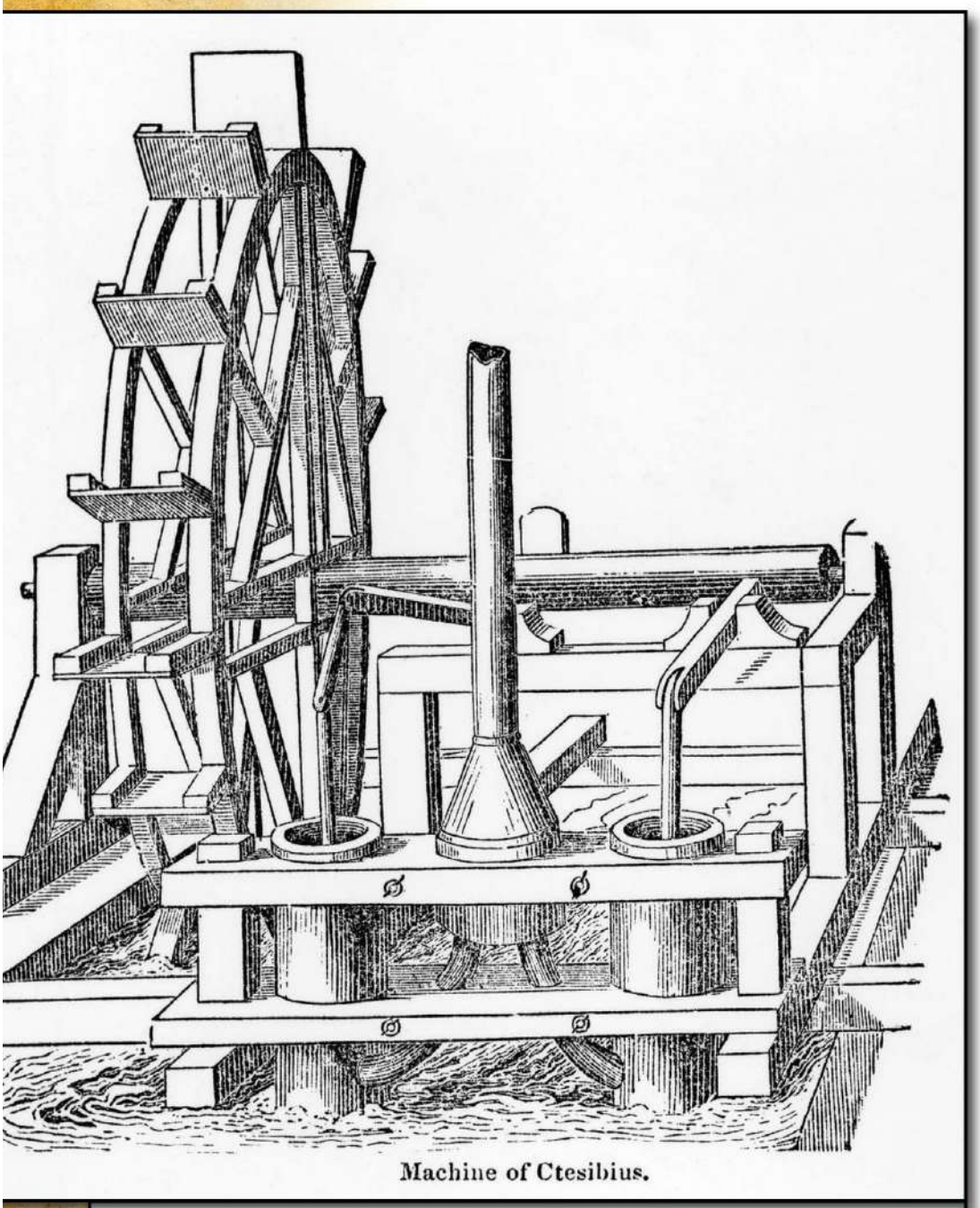


A water-driven pump from the 2nd century BCE designed by Greek invent Ctesibius



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The Romans were responsible, through the application and development of available machines, for an important technological transformation: the widespread introduction of rotary motion. This was exemplified in the use of the treadmill for powering cranes and other heavy lifting operations, the intro- duction of rotary water-raising devices for irrigation works (a scoop wheel powered by a treadmill), and the development of the water- wheel as a prime mover. The ıst-century-BCE Roman engineer Vitruvius gave an account of watermills, and by the end of the Roman era many were in operation.

BUILDING

Though many buildings of the Greeks sur- vive as splendid monuments to the civilized communities that built them, as technologi- cal monuments they are of little significance. The Greeks adopted a form of column and lin- tel construction that had been used in Egypt for centuries and was derived from experience of timber construction. In no major sense did Greek building constitute a technological innovation. The Romans copied the Greek style for most ceremonial purposes, but in other respects they were important innovators in building technology. They made extensive

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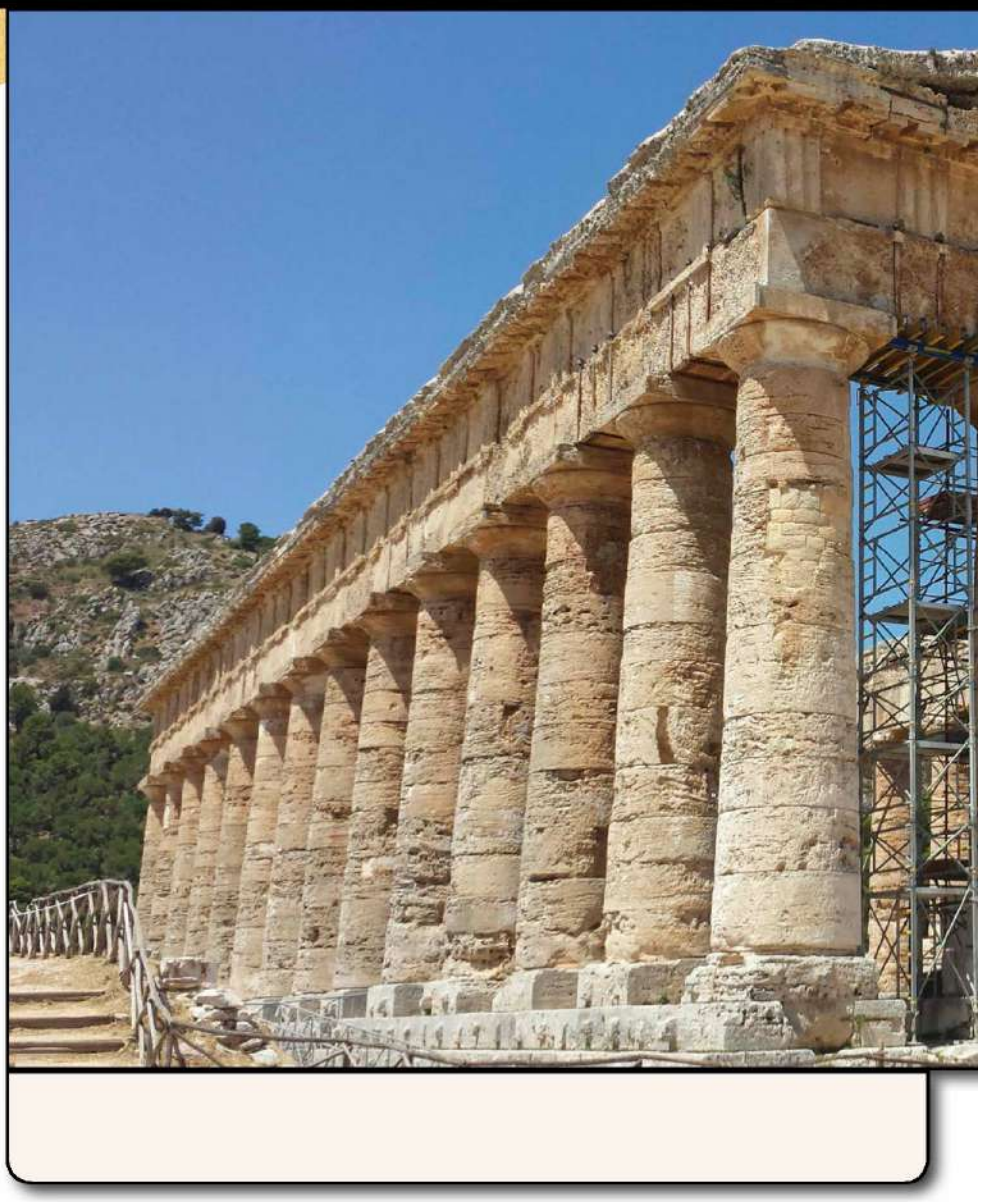

A Greek temple, an example of ancient Greek architecture

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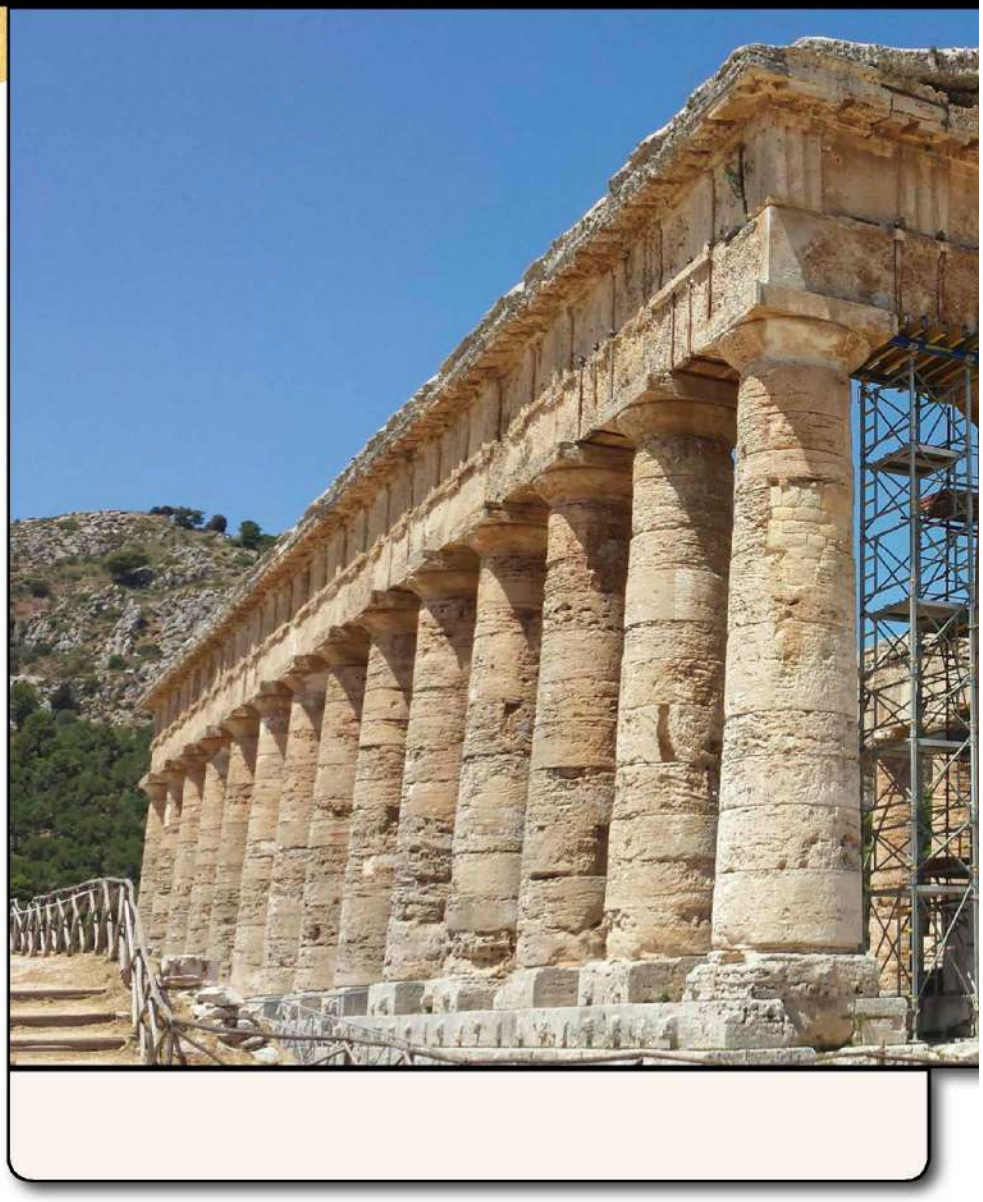

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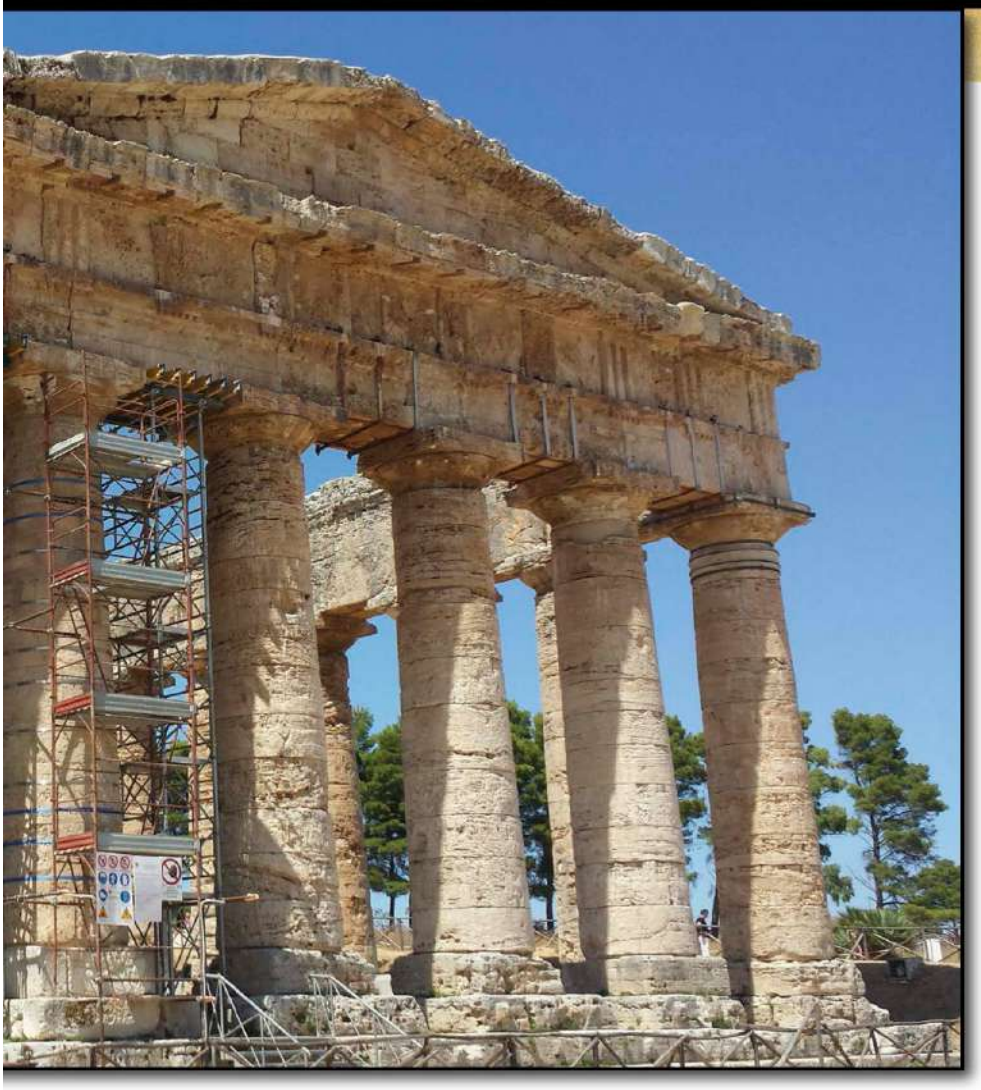

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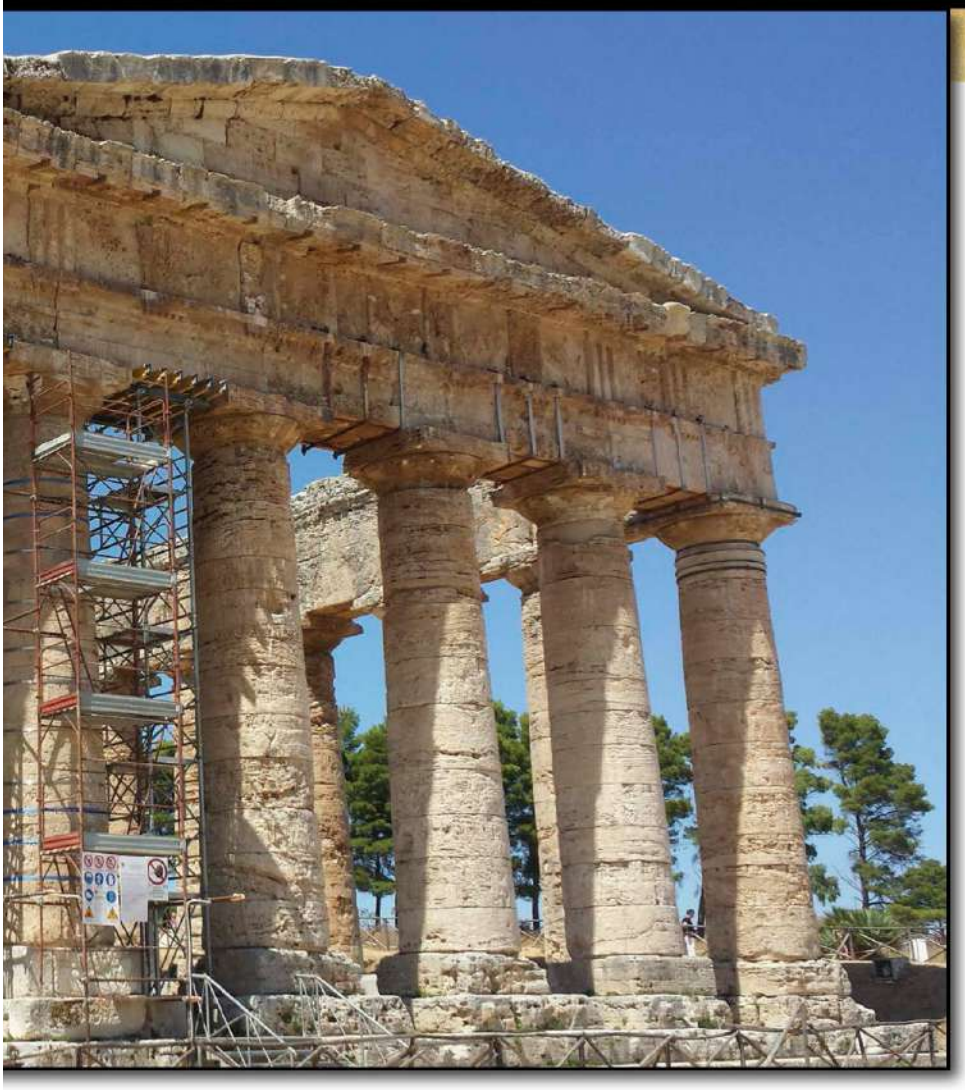

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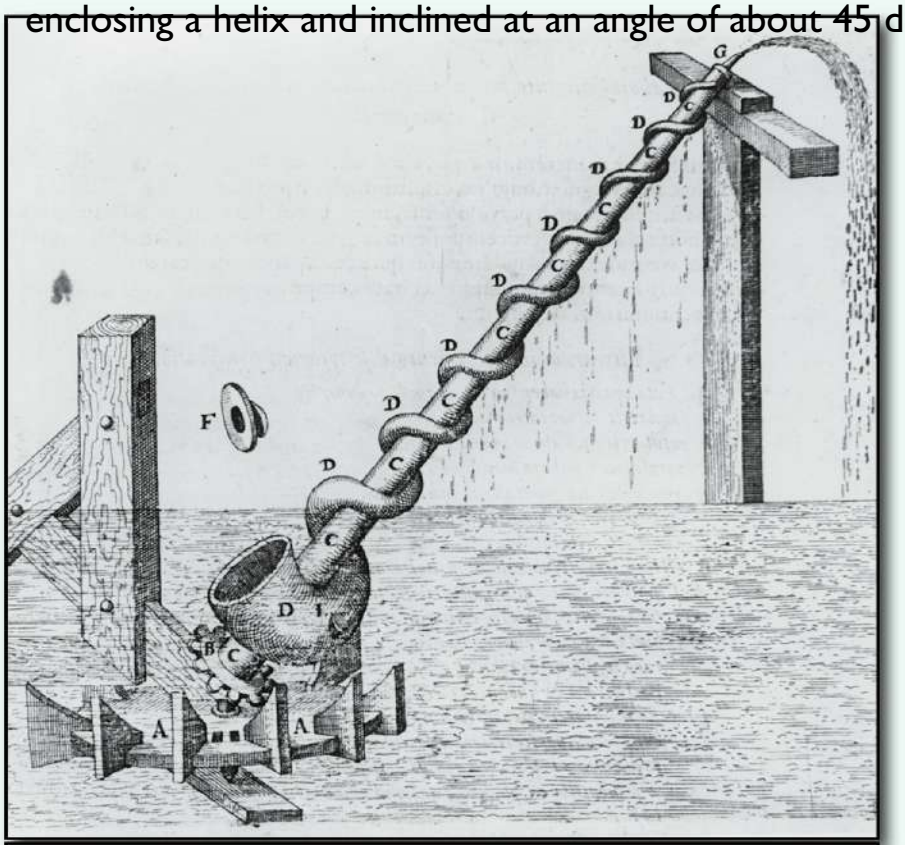

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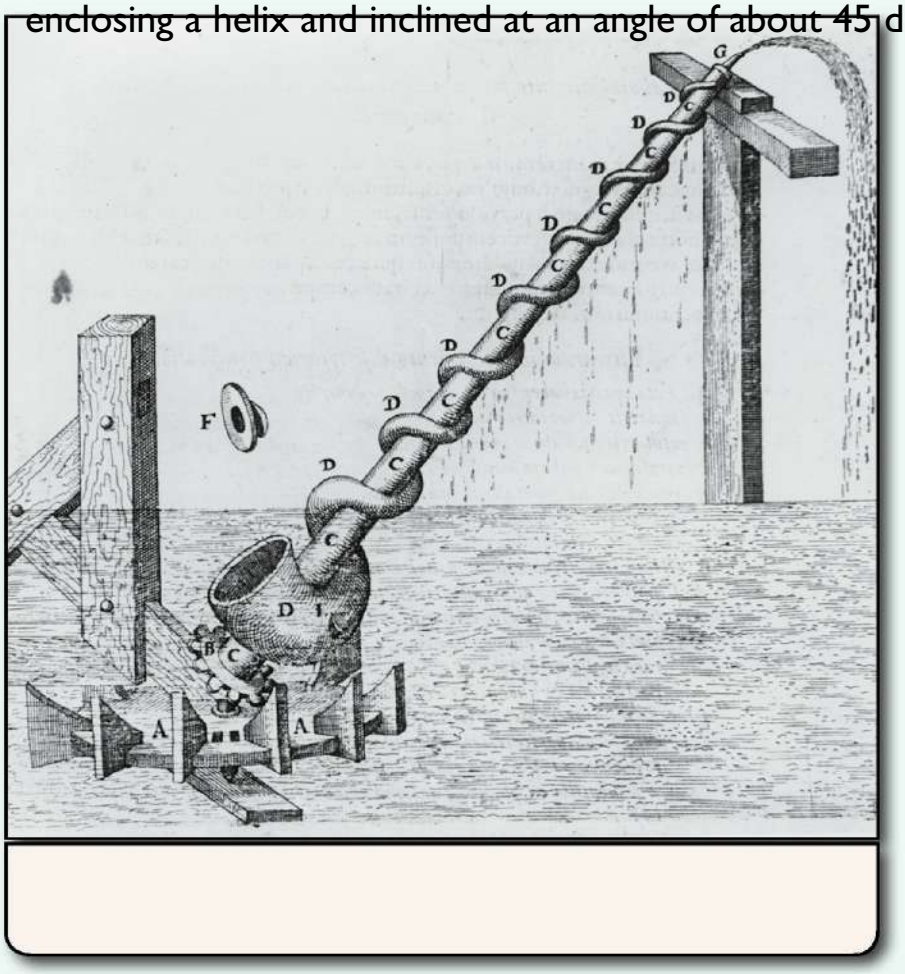

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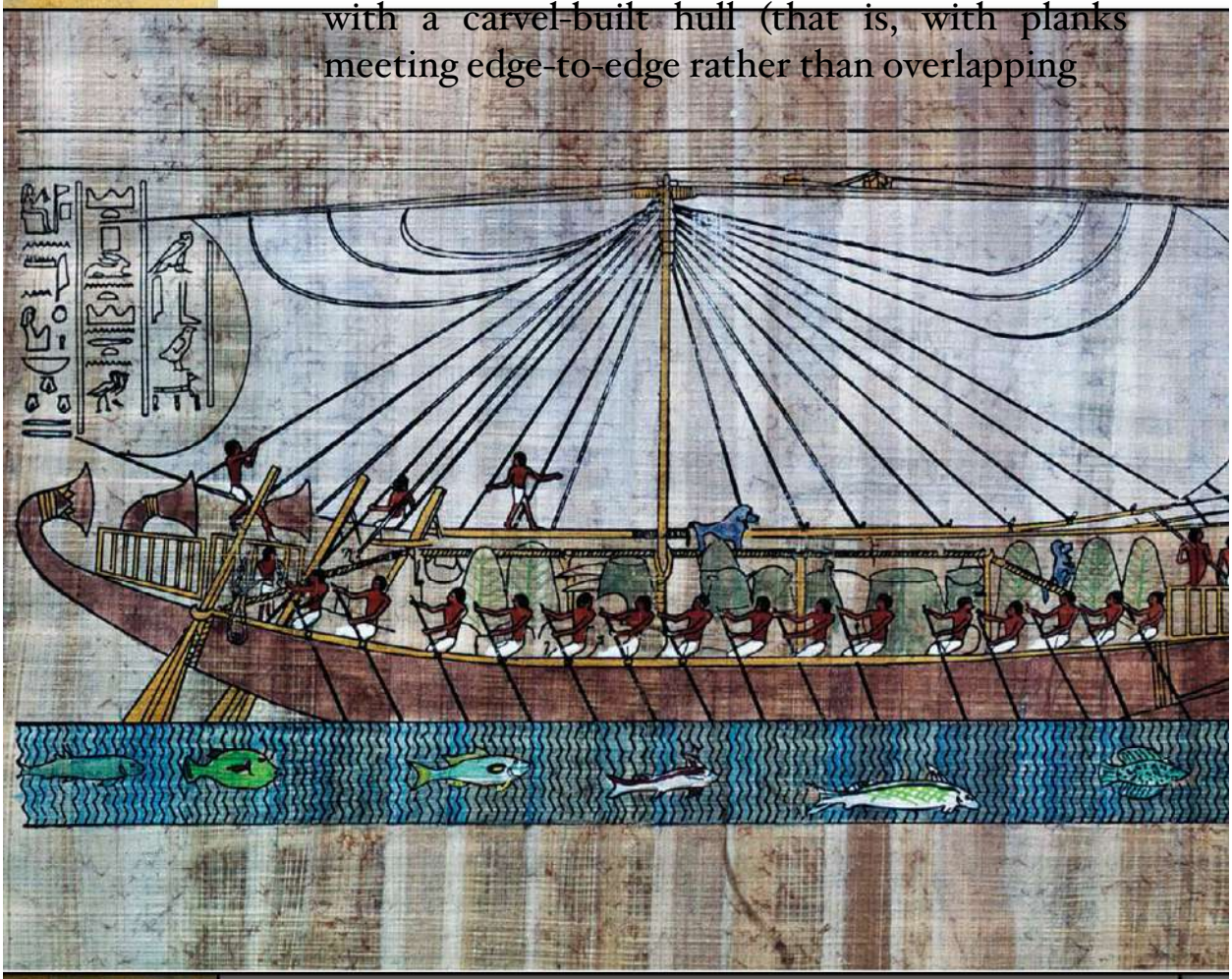
Transport, again, followed earlier precedents, the sailing ship emerging as a seagoing vessel with a carvel-built hull (that is, with planks meeting edge-to-edge rather than overlapping



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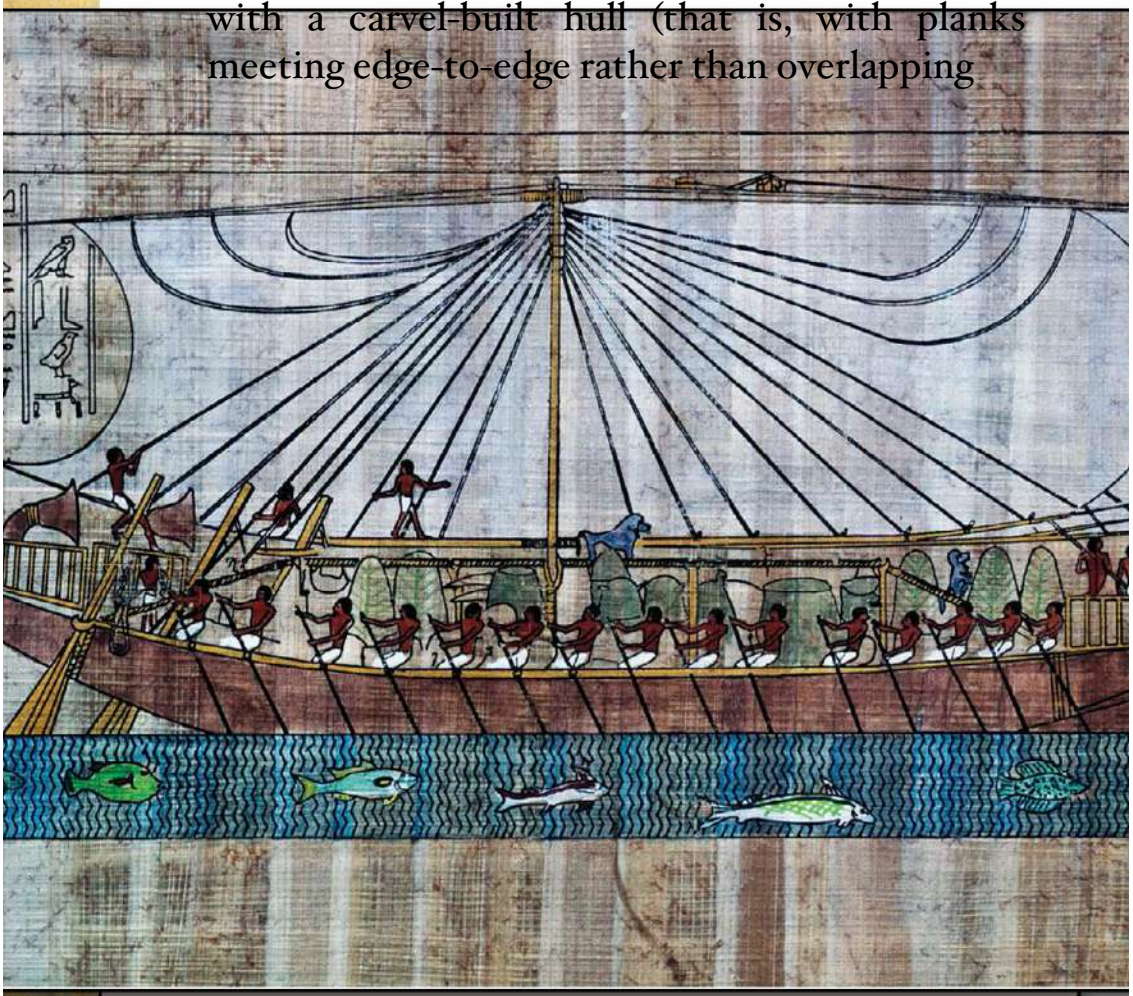

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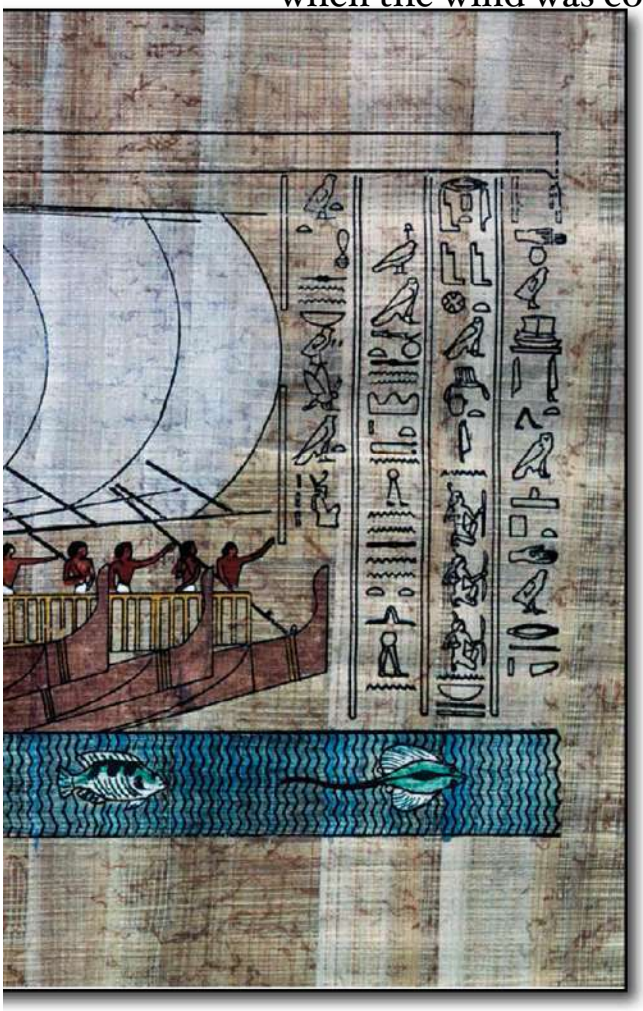
as in clinker-built designs), and a fully developed keel with stempost and sternpost. The Greek sailing ship was equipped with a square or rectangular sail to receive a following wind and one or more banks of oarsmen to propel the ship when the wind was contrary. The Greeks began to develop a specialized fighting ship, provided with a ram in the prow, and the cargo ship, dispensing with oarsmen and relying entirely upon the wind, was also well established by the early years of Classical Greece. The Romans took over both forms, but without significant innovation. They gave much more attention to inland transport than to the sea, and they constructed a remarkable network of carefully



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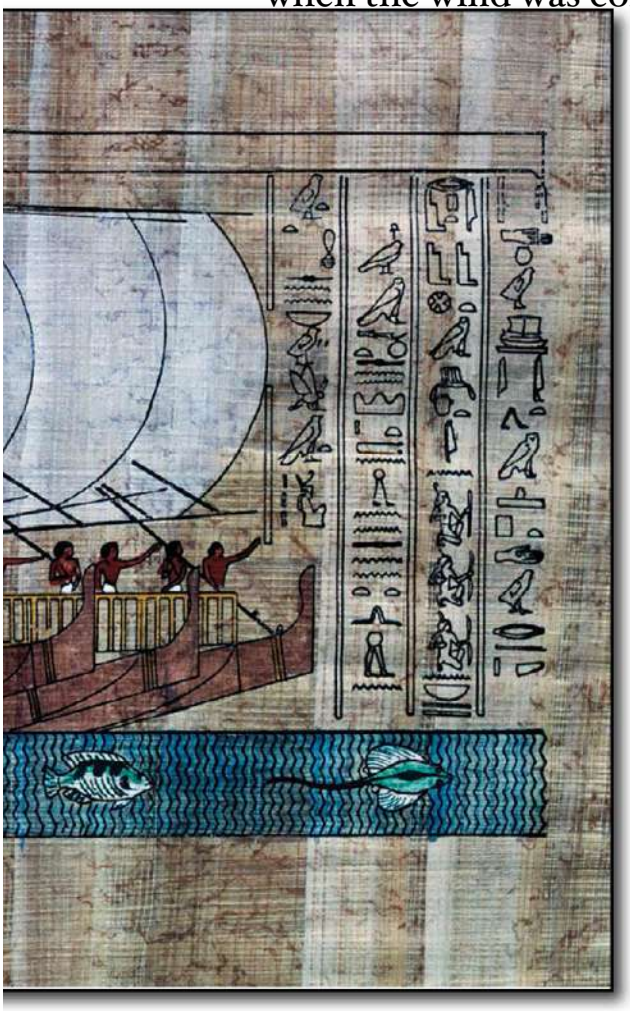

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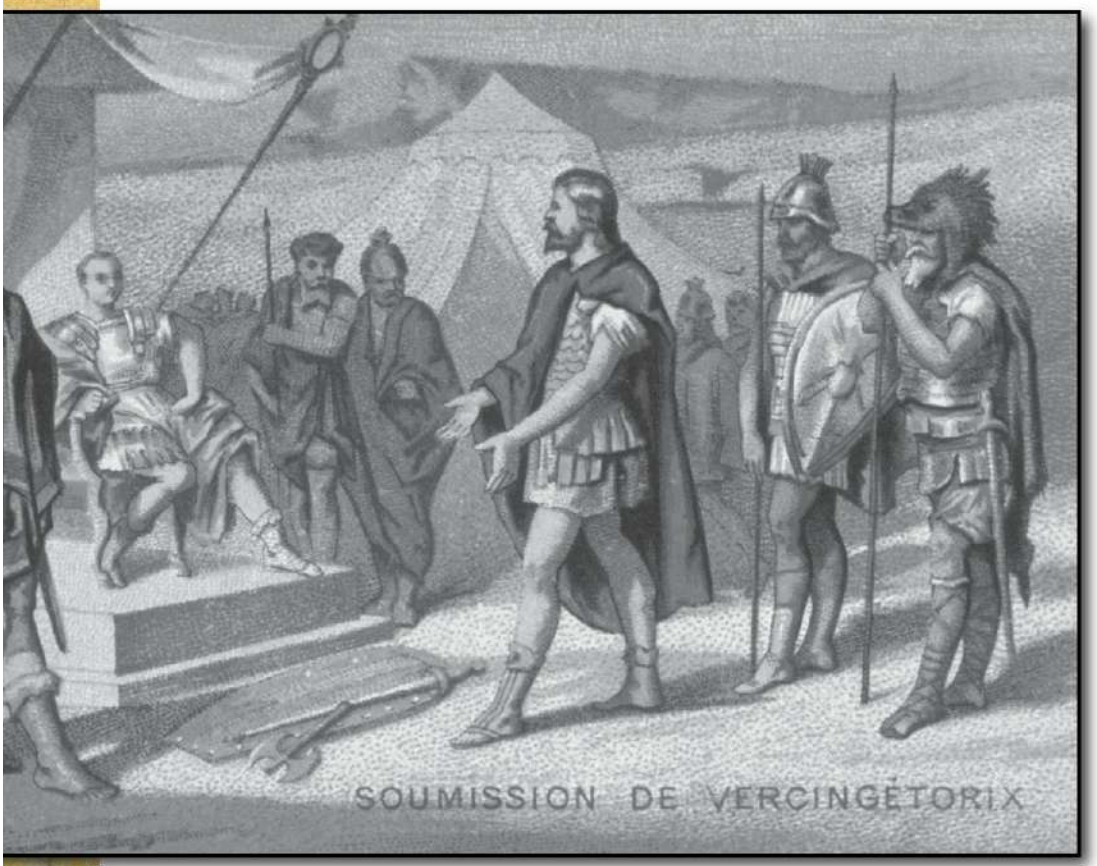

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Military Technology

Roman military technology was inventive on occasion, as in the great siege catapults, depending on both torsion and tension power. But the standard equipment of the legion- naire was simple and conservative, consisting of an iron helmet and breastplate, with a short sword and an iron-tipped spear. As most of their opponents were also equipped with iron weapons and sometimes with superior devices, such as the Celtic chariots, the Roman military achievements depended more on organization and discipline than on technological superior- ity. See Chapter 5 for more details.

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Chapter

AGRICULTURAL TECHNOLOGY

Over time, some plants and animals have become domesticated, or dependent on human interventions for their long-term propagation or survival. Domestication is a biological process in which, under human selection, organisms develop characteristics that increase their utility, as when plants pro- vide larger seeds, fruit, or tubers than their wild progenitors.

Agriculture developed independently in many regions of the world. It was the first profound change in the relationship between fully modern humans and the environment: people evolved into their current form some 200,000–100,000 years ago, yet they did not begin to engage in agriculture until about 15,000–10,000 years before the present.

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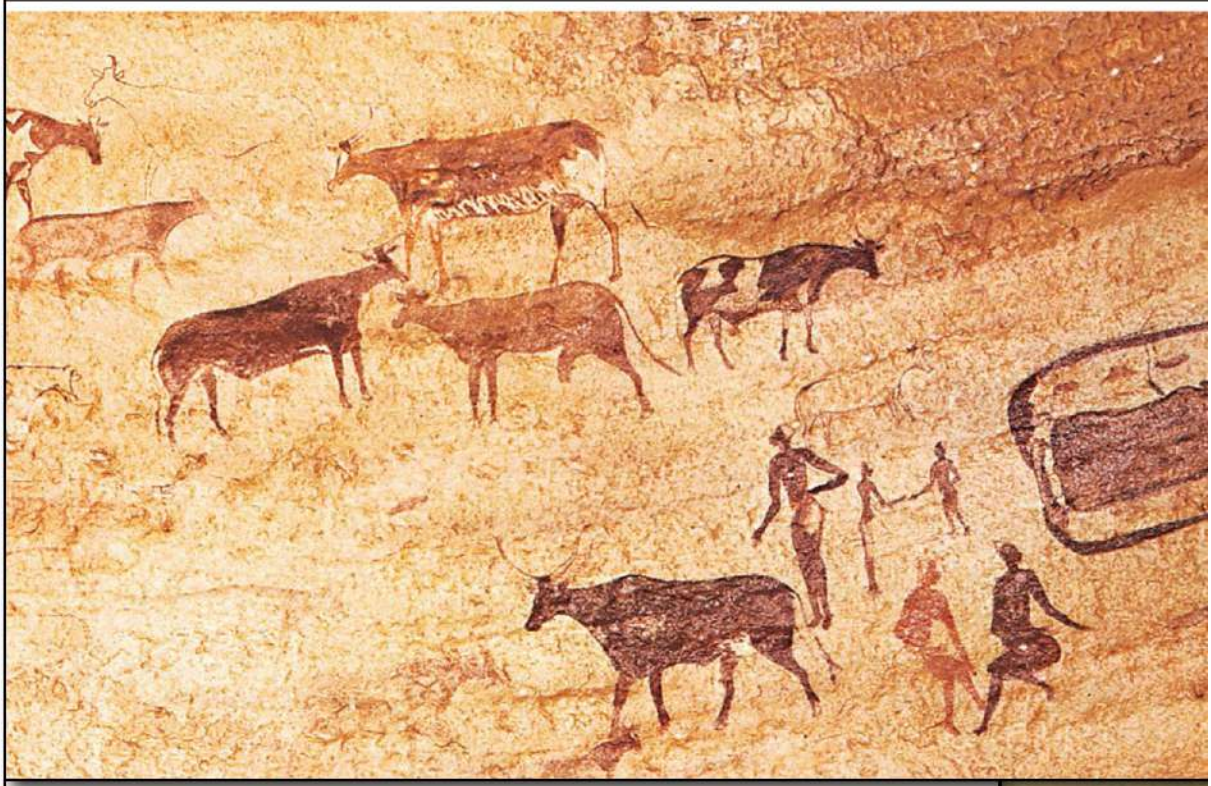

A cave painting of herdsmen and cattle, from Tassili-n-Ajjer, Algeria

HOW AGRICULTURE AND DOMESTICATION BEGAN

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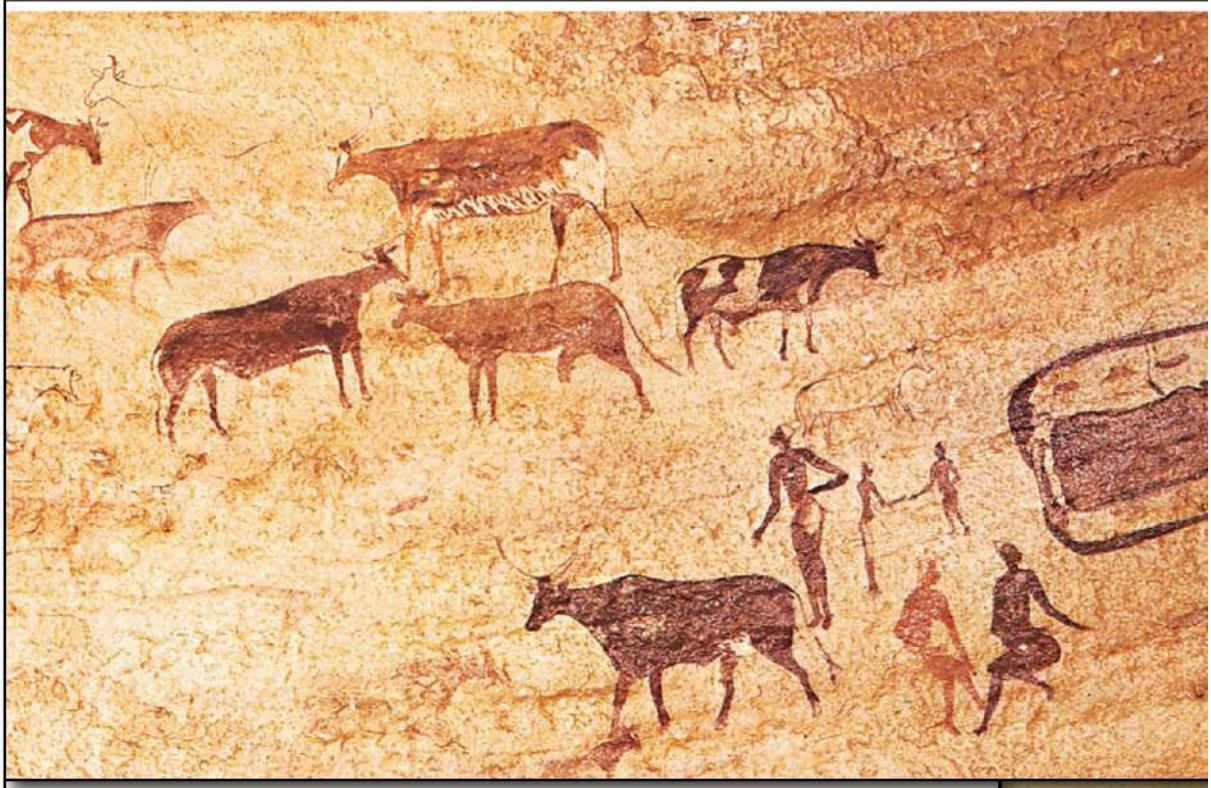

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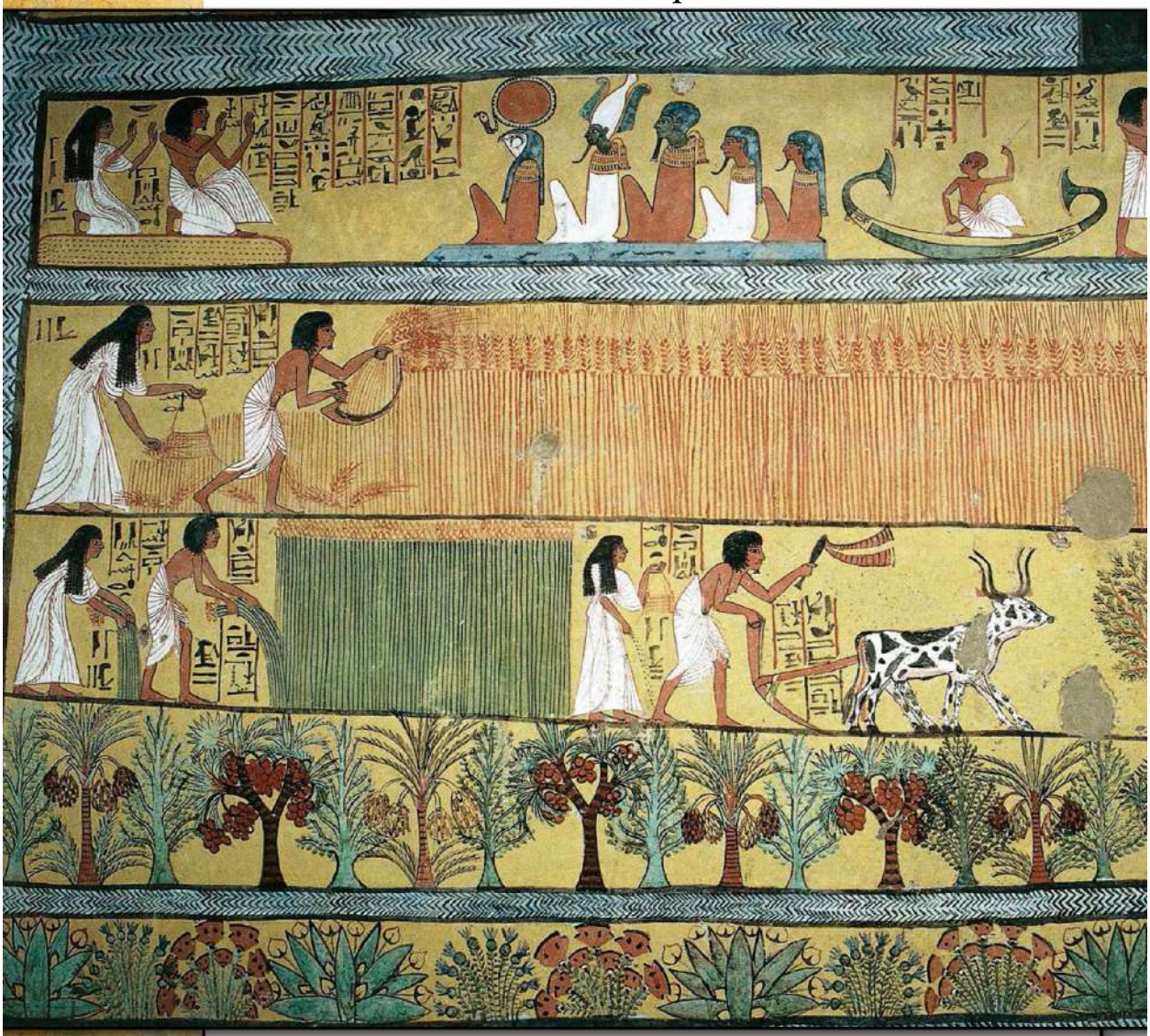

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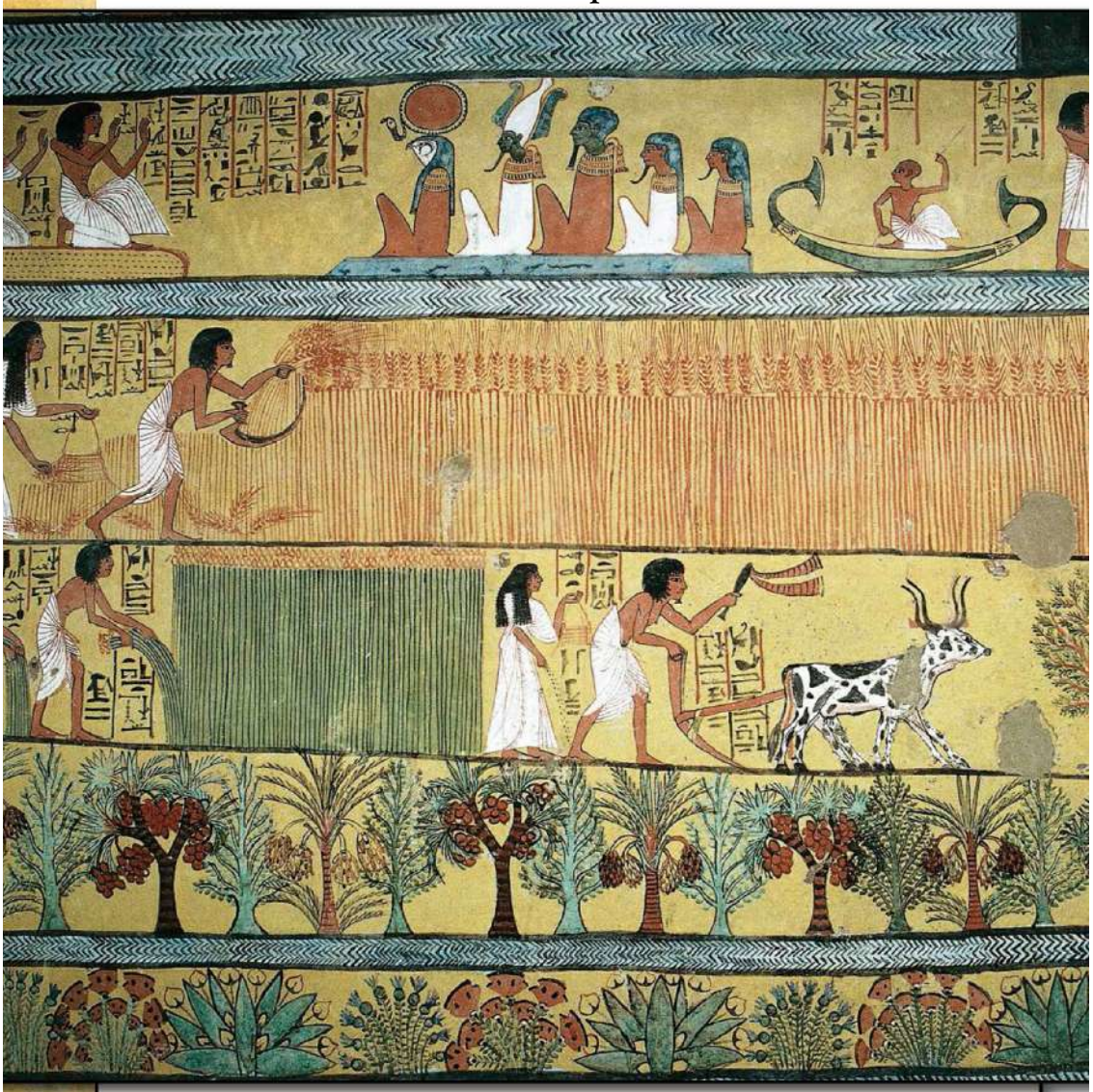
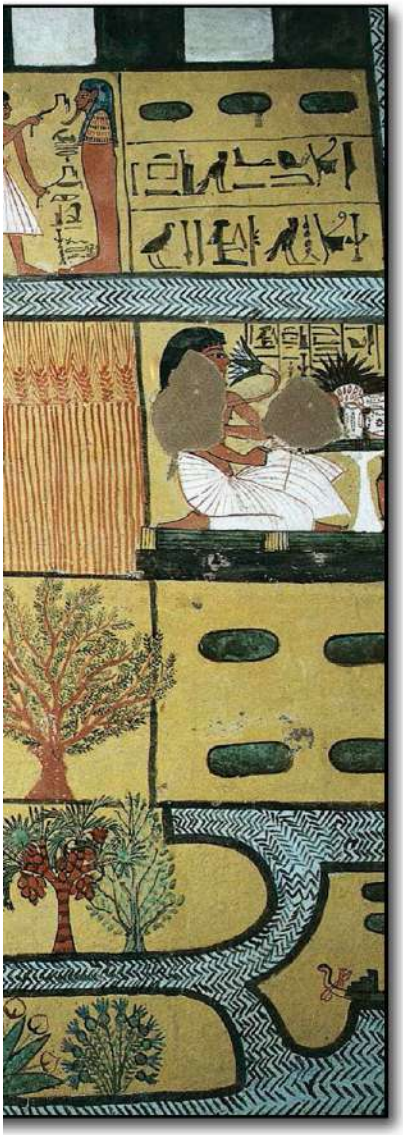


This fresco depicts agricultural scenes from Egypt's New Kingdom Dynasty XIX, c. 1292 to 1187 BCE.

cultural responses that ensued, the specific timing of the appearance of agricultural communities in different regions, or the specific regional impact of climate change on local environments. By studying populations that did not develop intensive agriculture or certain cultigens, such as wheat and rice, archaeologists narrow the search for causes. For instance, Australian Aborigines and many of the Native American peoples of western North America developed com- plex methods to manage diverse sets of plants and animals, often including (but not limited to) cul- tivation. These practices may be representative of activities com- mon in some parts of the world before 15,000 years ago.



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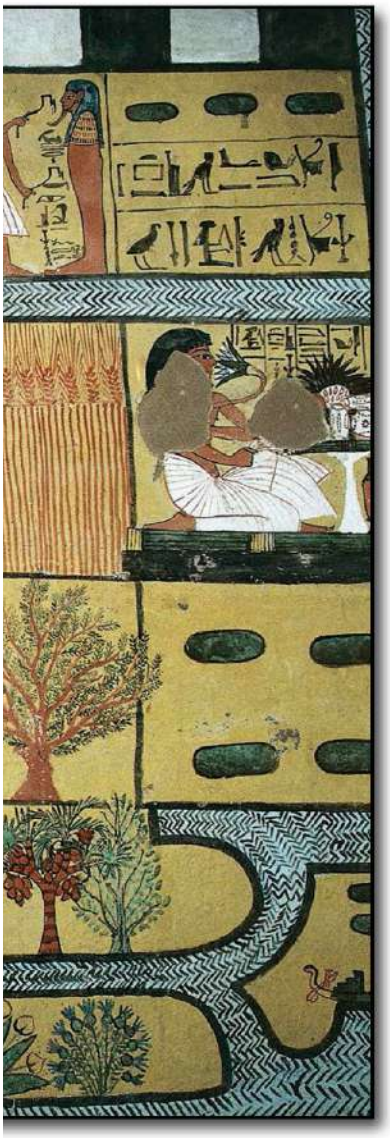

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The development of agriculture involves an intensification of the processes used to extract resources from the envi- ronment: more food, medicine, fibre, and other resources can be obtained from a given area of land by encourag- ing useful plant and animal species and discouraging others. As the productiv- ity and predictability of local resources increased, the logistics of their procure- ment changed, particularly regarding the extent to which people were prepared to travel in order to take advantage of seasonally available items. Group com- position eventually became more stable, mobility declined, and, as a consequence, populations increased.

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EARLY AGRICULTURAL SOCIETIES

In the Old World, settled life developed on the higher ground from Iran to Anatolia and the Levant and in China in the semiarid loess plains and the humid Yangtze valley. In contrast, the earliest civilizations based on complex and productive agriculture developed on the allu- viums of the Tigris, Euphrates, and Nile rivers. Villages and townships existed in the Euphrates valley in the latter part of the 7th millennium BP. Soon the population was dispersed in hamlets and villages over the available area. Larger settlements provided additional services that the hamlets themselves could not.

SUMER

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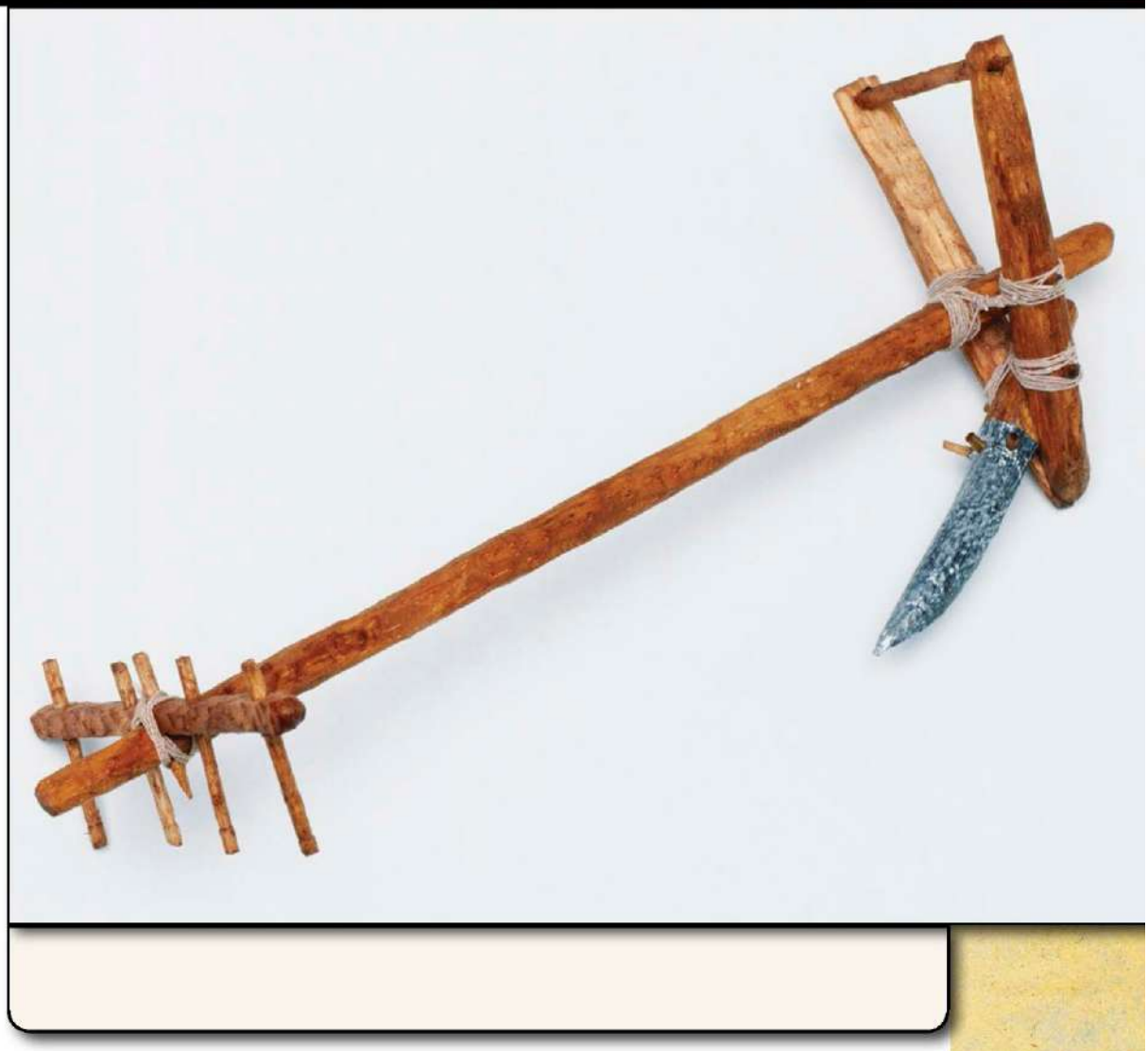

A re-creation of a Sumerian plow

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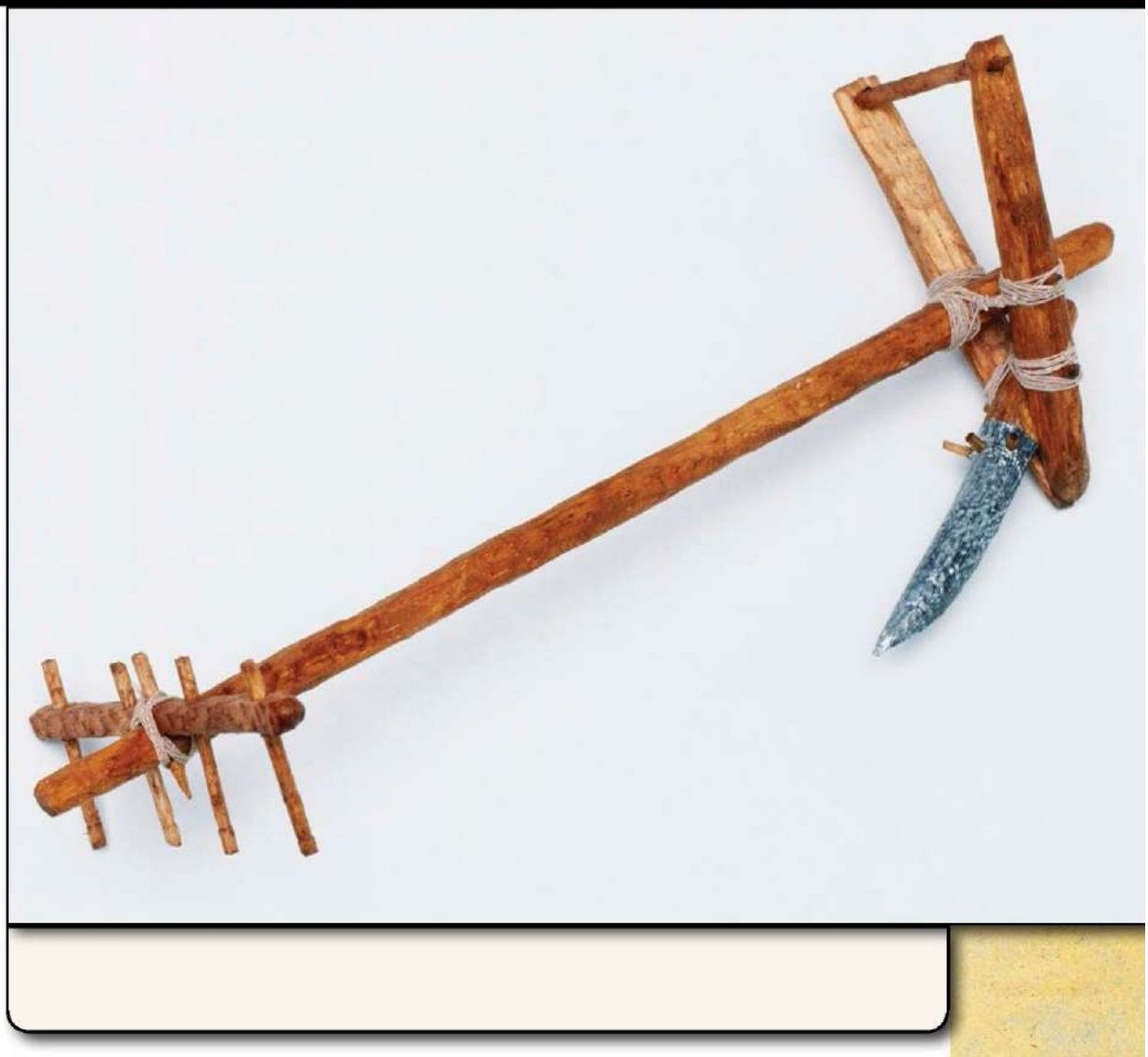

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Eventually, Formative groups such as the Olmec, known for carving colossal stone heads, developed large prosperous towns. Larger ter- ritorial units developed about 2000 BP, and Formative cultures were eventually eclipsed by the Maya, Toltec, and Aztec empires. Food was supplied to these empires' large urban centers by a combination of rain-fed swidden fields (temporary agricultural plots produced by cut- ting back and burning off vegetative cover) and irrigated tropical lowland field systems.

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The long use of swidden agriculture in South America is related to its appropriateness for the tropical lowlands: it helped to maintain local soil fertility and mimicked the diverse tropi- cal ecosystem. Labor-intensive technology was not required. Some researchers have proposed that the nature of tropical lowland ecosystems cannot be understood without acknowledging the long- term presence of swidden agriculture.

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Other groups used a variety of agricultural techniques: crops were grown on alluvium caught behind check dams, low walls built in arroyos to catch runoff from the rains; hill- side contour terraces helped conserve soil and water; and bordered gardens and irrigation sys- tems were devised. At Snaketown, a Hohokam site in Arizona, a complex canal system sup- ported a large population. Many canals were at least 2 meters (6.5 feet) deep and 3 meters (10 feet) wide. In the Phoenix area, hundreds of kilometers of canals have been found.

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AGRICULTURE IN ANCIENT ASIA

In eastern Asia, a number of advances in agricultural tools, practices and techniques, and the choice of crops themselves led to a great increase in efficiency and productivity. As in other parts of the world, technological improvements in agriculture often had wide-ranging sociopolitical and socioeconomic effects as well.

Tools and Techniques in China

The first significant revolution in Chinese agricultural technology occurred when iron agricultural implements became available to the Chinese peasantry. The earliest iron plow found in northern Henan dates from the Warring States period (475–221 BCE) and is a flat V-shaped iron piece that must have been mounted on wooden blades and handles. It was small, and there is no evidence that draft

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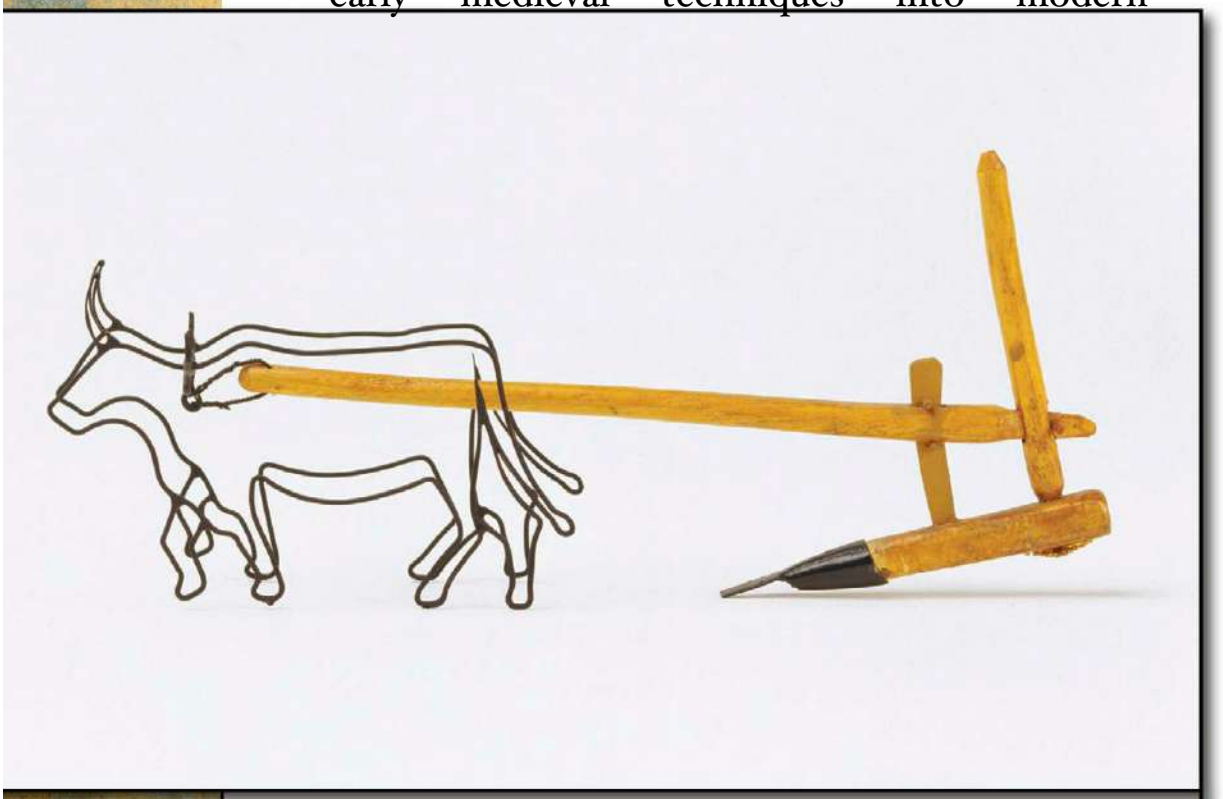

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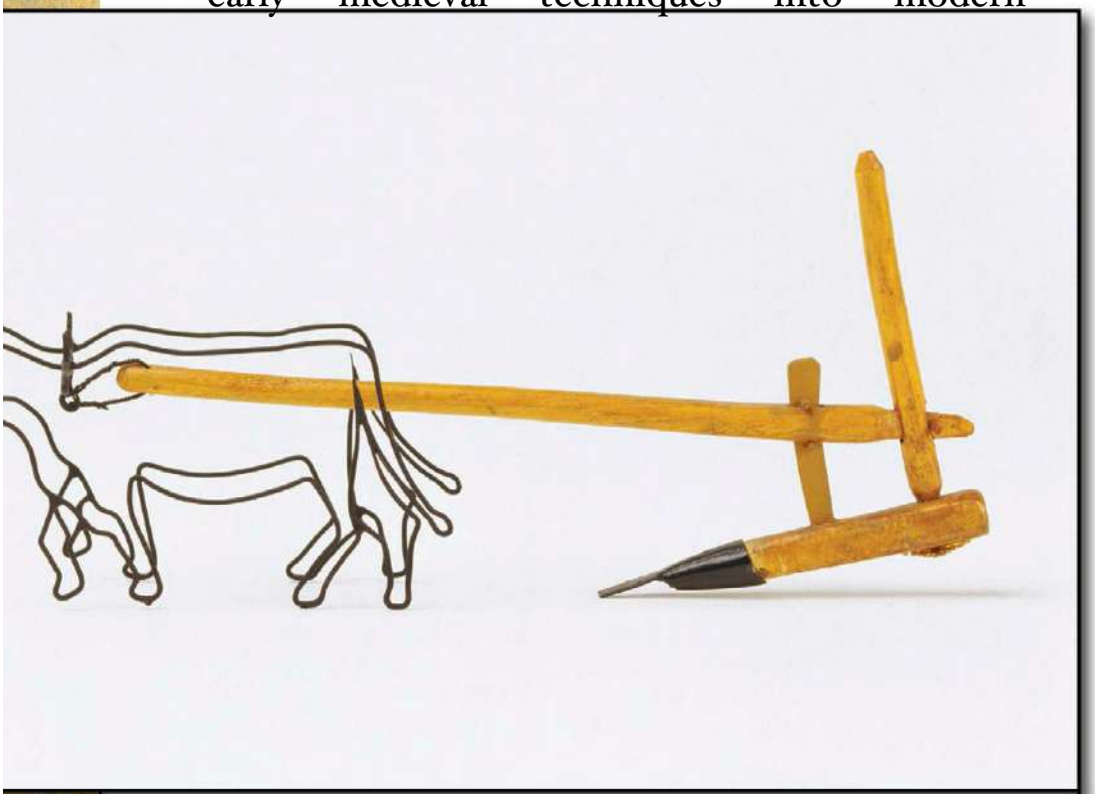

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Over the past millennium, the revolution in Chinese agriculture was not in mechanical or chemical technology but rather in the biological sphere: in crops, cropping systems, and land utilization. Under increasing population pressures, cultivation was forced to become more labor-intensive and also to expand into the sandy loams, the arid hills, and the upper reaches of lofty mountains. Lacking major technological inventions, the Chinese peasant had to expand the area under cultivation by finding suitable crops for inferior land.

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The second stage, dating to about 7000 BP at Mehrgarh, includes evidence of another crop, cotton. It is quite likely a local domes- ticate. Other important crops with histories in the Indian subcontinent are mung beans (*Vigna radiata*), black gram (*Vigna mungo*), hor- segram (*Macrotyloma uniflorum*), and pigeon pea (*Cajanus cajun*), all of which appear after about 5000 BP. Rice is present by about 7000 BP (and possibly earlier), but in this early period its status as a cultigen is unclear; fully domesticated rice and little millet (*Panicum*

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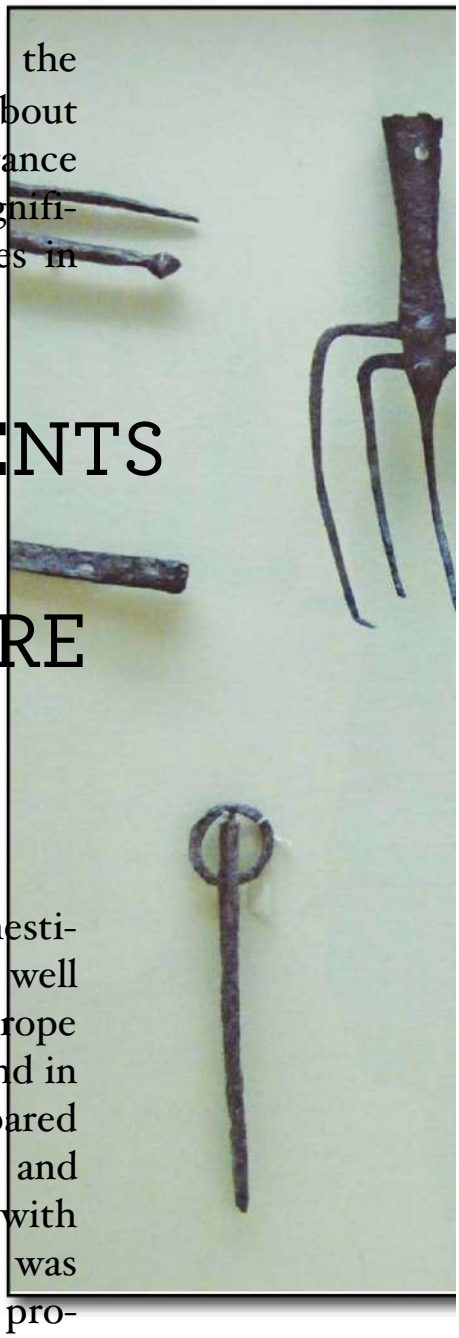

IMPROVEMENTS IN AGRICULTURE IN THE WEST

Crop farming and domestication of animals were well established in western Europe by Roman times. The ground in Roman holdings was pre- pared with hand tools, hoes, and mattocks, doubtless edged with bronze or iron. There was already emphasis on production of wine and oil for sale, rather than cultivation of cereal crops. Tools included carts, plows and plowshares, yokex, ox harnesses, harrows, manure hampers and baskets, packsaddles and pads, spades, shovels, rakes, scythes, axes, wedges, in addition to overseers, housekeepers, laborers

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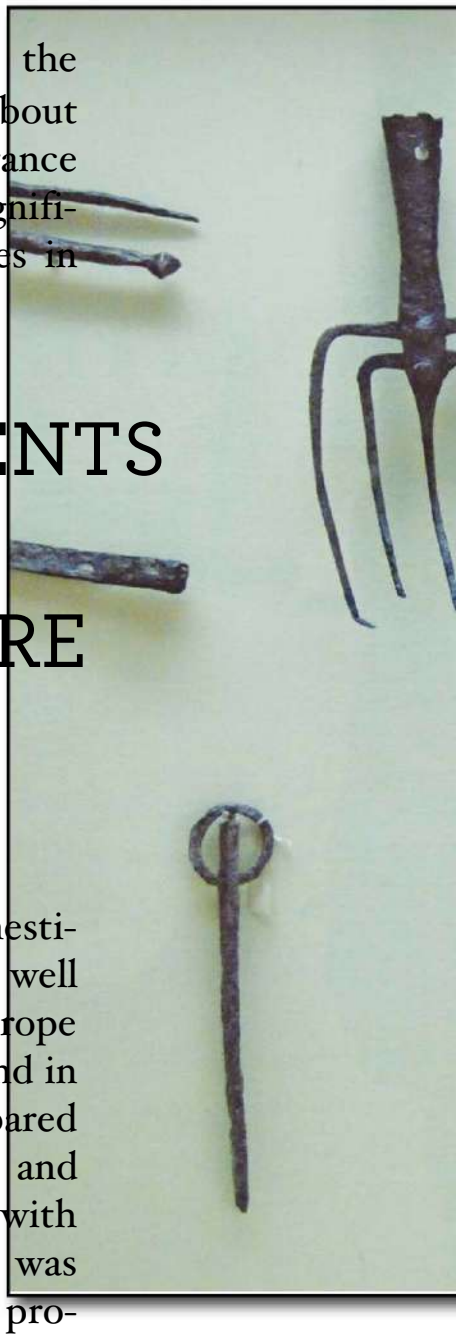

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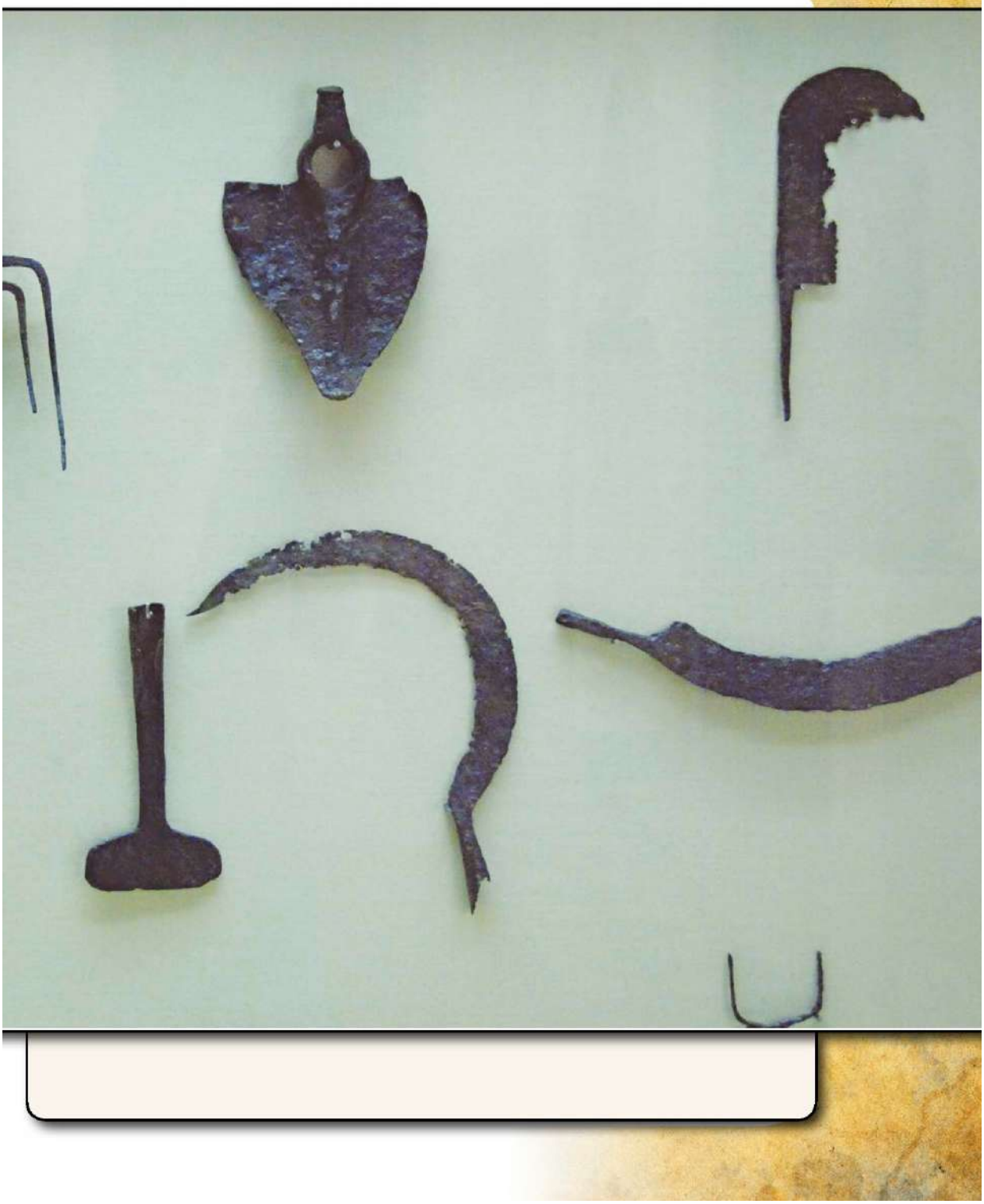

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Although it was realized that different soils were better suited to some crops than to oth- ers, the same piece of land was used for all crops. A specific crop, however, was grown in alternate years in what is known as the two- field, or crop- and-fallow, system. Then as now, wheat was mostly sown in autumn. Barley was a spring-sown crop, as were most others.

The harvest was reaped with a curved sickle, though a short-handled sickle was sometimes used along with a short-handled hooklike implement in the left hand to draw together enough grain to be cut at one stroke. In Gaul a reaper was used, with a cart which had a comblike device that tore off the ears as the vehicle was pushed through the crop. Animals were used to thresh grain. Winnowing was still done by tossing grain in the air when there was a favorable wind to blow away the

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Chapter

MILITARY TECHNOLOGY

The earliest evidence for a specialized military technology are the stone walls of Jericho, which date from about 8000 BCE, though when the defenses of Jericho were built, humans already had been using weapons of the hunt for millennia. It is evident that the technical problems of hafting a stone onto a handle were not easily solved. Well-made maces were for a long time few in number and wielded only by champions and rulers. The advent of the mace as a purposely designed offensive weapon opened the door to the conscious innovation of specialized military technology. By the mid- dle of the 3rd millennium BCE, copper was employed in mace heads, yielding higher den- sity and greater crushing power. It represents one of the earliest significant uses of metal for other than ornamental purposes.

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4th century BCE Iranian mace head

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Metalworking was applied to the produc- tion of weaponry as early as, or earlier than, any other economically significant pursuit. Precious metals, with their low melting points and great malleability, were worked first; next came copper—at first pure, then alloyed with arsenic or tin to produce bronze—and then iron. A remarkable phenomenon was the per- sistence of weaponry made of the soft, rare metals such as gold, silver, and electrum (a naturally occurring alloy of gold and silver) long after mechanically superior materials had become available. For example, helmets and body armor of electrum, which were prob- ably intended for actual use, have been found in Egyptian and Mesopotamian burials dating from the 2nd and 3rd millennia BCE.

ANTIQUITY AND THE CLASSICAL AGE, C. 1000 BCE–CE 400

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victory. Mastery of wood and bronze for military purposes reached a level during this period that was seldom, if ever, attained afterward. Military mobility was gained by the use of harnesses and animal power for hauling purposes, though human porters proved just as efficient. Therefore pack animals carried rations, tents, and firewood, and carts were used only for bulky items such as siege engines, while sol- diers carried all personal equipment.

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DEFENSIVE WEAPONRY

The design and production of individual defensive equipment was restricted by the shape of the human form that it had to protect; at the same time, it placed heavy demands on the smith's skills. The large areas to be protected, restrictions on the weight that a combatant could carry, the difficulty of forging metal into the complex contors required, and cost all con- spired to force constant change.

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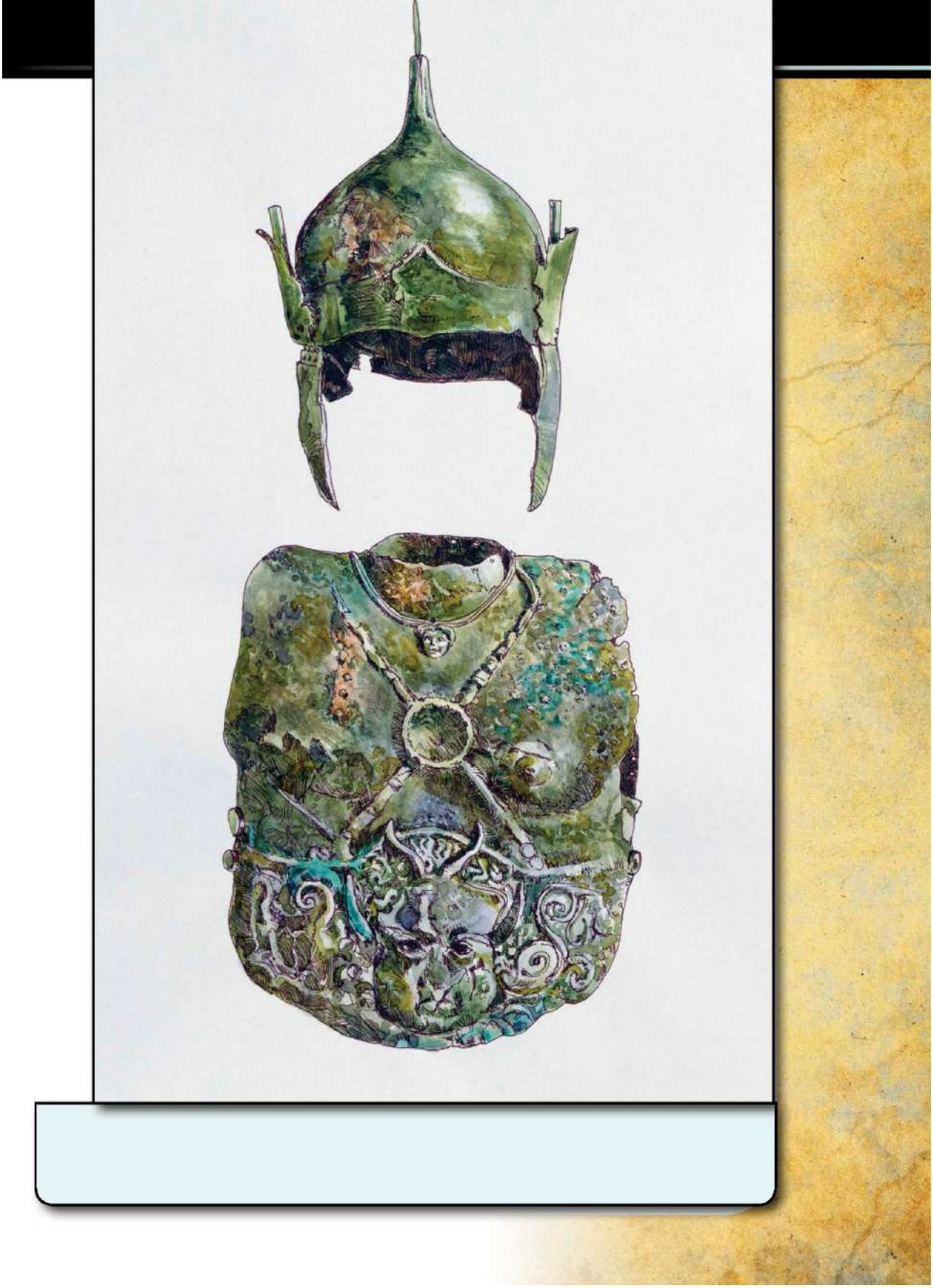
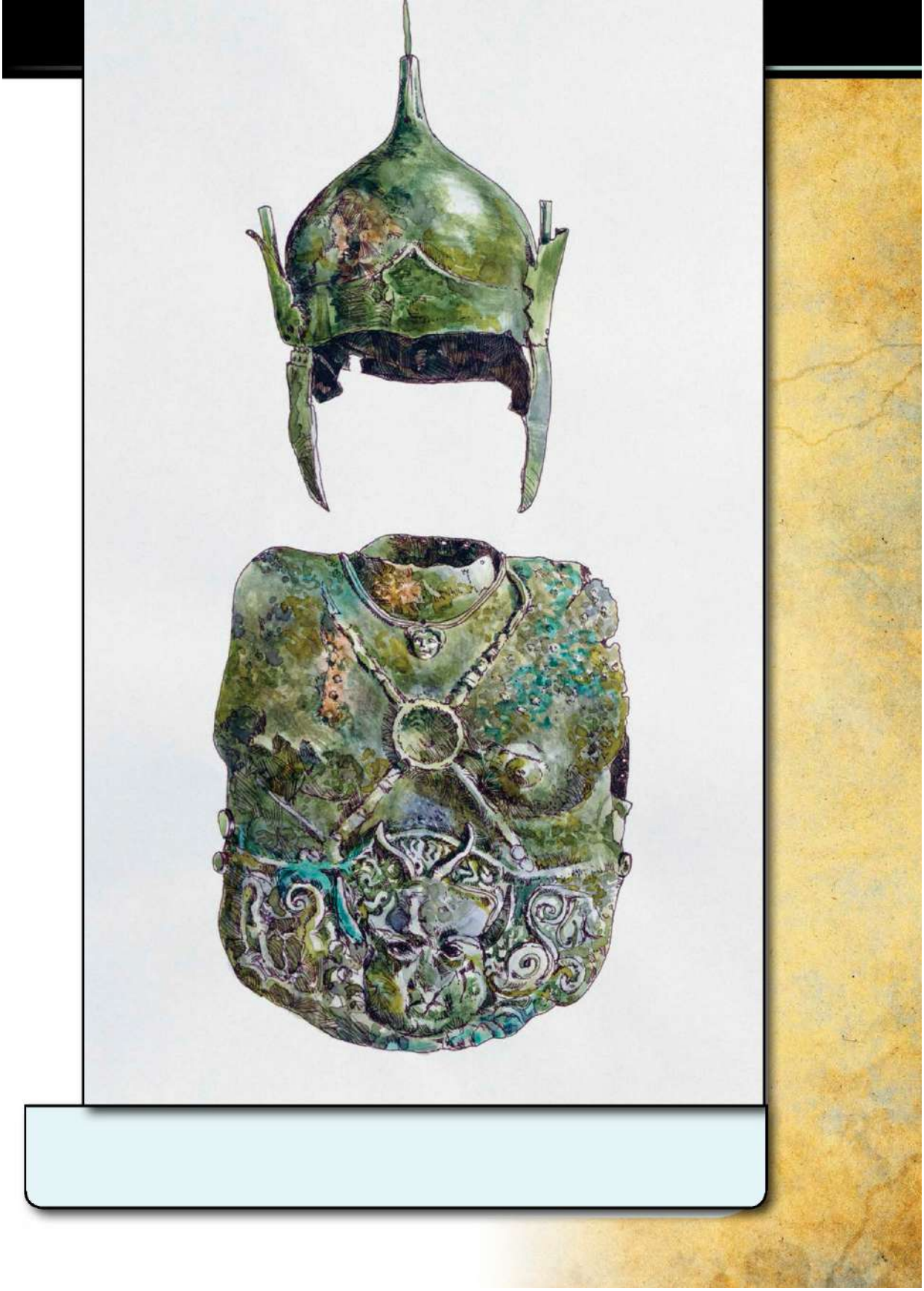


Drawing of a bronze Phrygian-type armor and helmet, 4th century BCE, Italy



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Helmets

Forging an integral, one-piece dome of metal capable of covering the entire head was extremely difficult. The Corinthian Greek helmet, a deep, bowl-shaped helmet of carefully graduated thickness forged from a single piece of bronze, probably represented the functional as well as aesthetic apex of the bronze worker's art. Many classical Greek helmets of bronze were joined by a seam down the crown.

Iron helmets followed the evolution of iron mail, itself a sophisticated and relatively late development. The legionnaire of the early Roman Republic wore a helmet of bronze, while his successor in the Empire of the 1st century CE wore one of iron.

Shields

Shields were used for hunting long before military application. The size and composition of shields varied greatly, depending on how it worked with the wearer's armor or weapon. The Greek hoplite acquired his name from the *hoplon*, a convex, circular shield, approximately three feet (90 centimeters) in diameter, made of composite wood and bronze. In the 4th cen- tury BCE, the soldier of the Roman Republic,

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Body Armor

Padded garments, and perhaps armor of hardened leather, preceded edged metal weapons. Next came small metal plates sewn onto a protective garment. By classical times, breastplates of bronze were commonplace among heavy infantry and elite cavalry. Greaves, defenses for the lower leg, closely followed the breastplate. Defenses for more remote por- tions of the body were probably not common in field service. Bronze was the most common metal for body defenses well into the Iron Age.

The first practical body armor of iron was mail, made of small rings of iron, typically of one-half-inch diameter or less, linked into a protective fabric. The fabrication of mail was extremelylabor-intensiveandcostly.Theearli- est mail was made of hand-forged links. Later, armorers used punches of hardened iron to cut rings from sheets. The Roman legionnaire was equipped with a *lorica hamata*, a mail shirt, from a very early date. Mail was extremely

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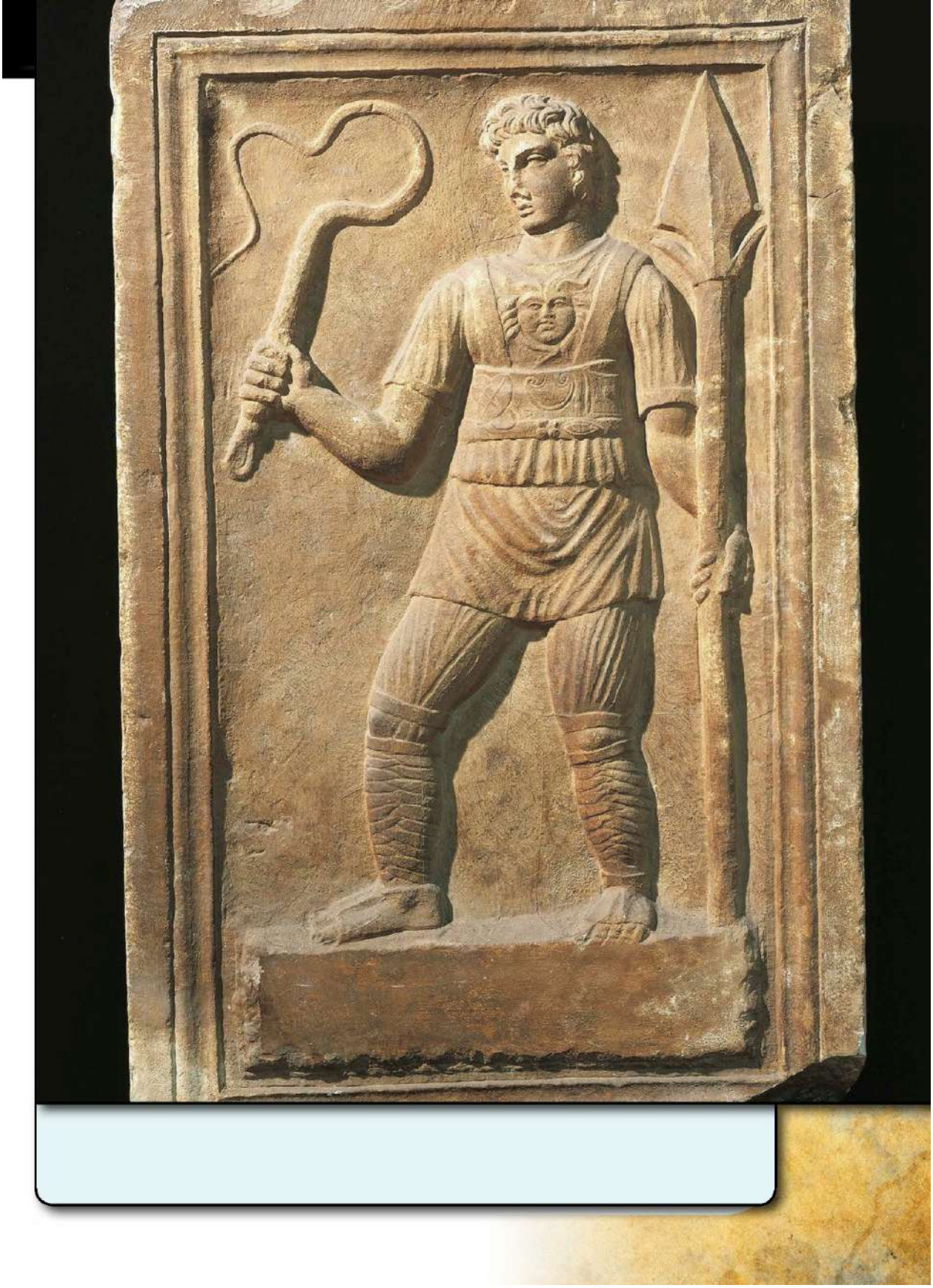
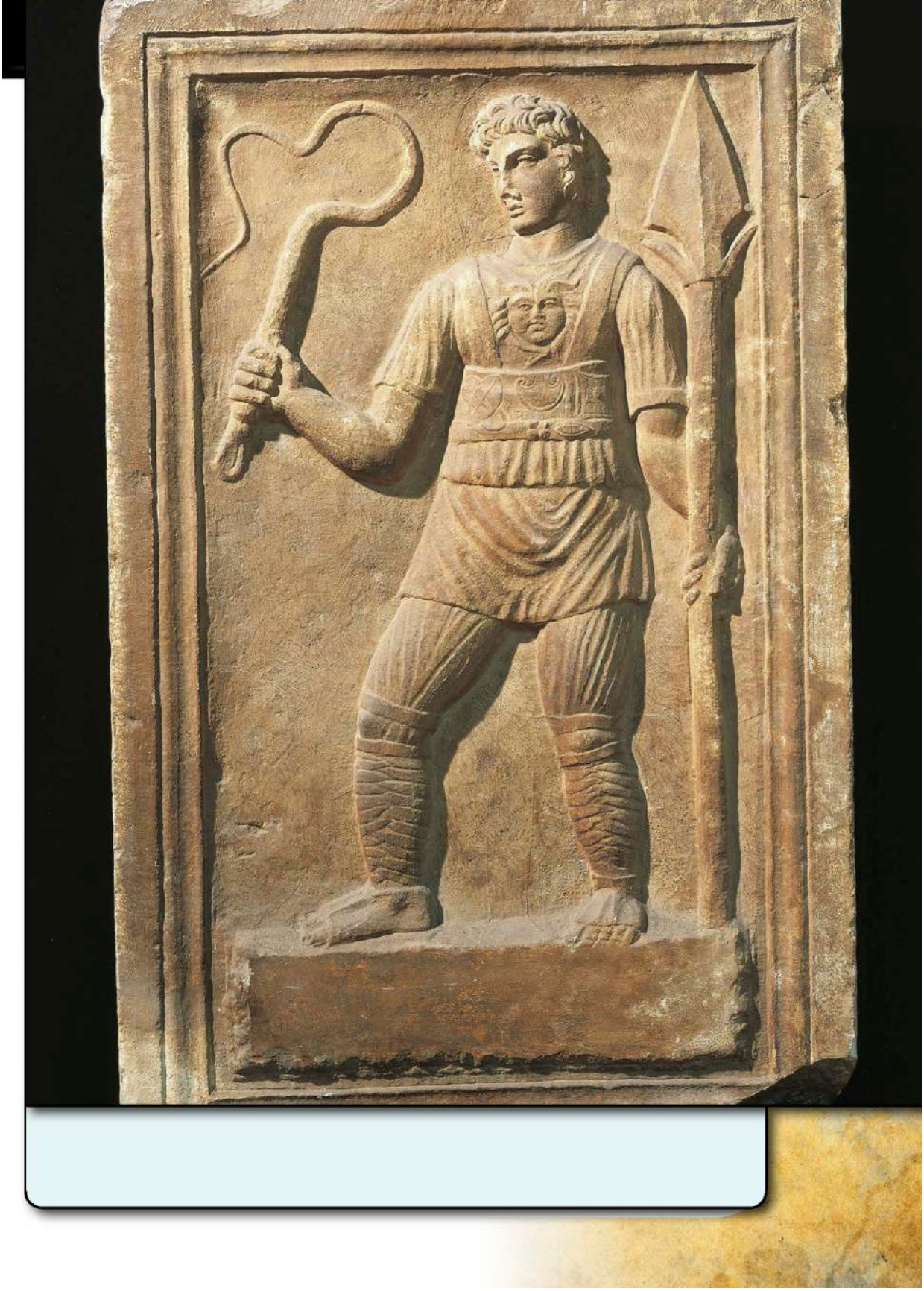


Roman depiction of a 1st-century gladiator in combat



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The *lorica segmentata* heralded the production of practical plate armor on a large scale. Classical plate armor probably provided bet- ter protection against smashing and heavy piercing blows, while a shirt of well-made mail covered more of the body and, hence, afforded better protection against slashing blows and missiles.

OFFENSIVE WEAPONRY

One of the most striking facets of ancient military technology is the early date by which individual weapons attained their form and the longevity of early offensive weapons concepts. Some of the weapons of antiquity disappeared or were modified, but with the exception of the halberd and crossbow, virtually every sig- nificant pre-gunpowder weapon was known in antiquity.

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The Spear

Early humans probably employed spears of fire-hardened wood, then spearheads of knapped stone. Bronze spearheads followed and were, with the piercing ax, the earliest significant military application of bronze. Spearheads were also among the earliest mili- tarily significant applications of iron. The spears of antiquity were relatively short, com- monly less than the height of the warrior, and typically were wielded with one hand. As defensive armor and other weapons of shock combat (notably the sword) improved, spear shafts were made longer. The Greek hop- lite's spear was about 9 feet (2.7 m) long; the Macedonian sarissa was twice that length in the period of Alexander's conquests, and it grew to some 21 feet (6.4 m) in Hellenistic times.

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The Javelin

Javelins, or throwing spears, were shorter and lighter than spears designed for shock com- bat and had smaller heads. Javelin troops were commonly used for skirmishing. A throwing string was sometimes looped around the shaft and tied to the thrower's finger to impart spin to the javelin on release. This improved the weapon's accuracy and probably increased the range and penetrating power by permitting a harder cast. Like the spear, the javelin was relatively unaffected by the appearance of iron and retained its characteristic form until it was finally abandoned as a serious weapon in the 16th century.

The Sling

The sling was simple in design, but difficult in practice. It consisted of two cords or thongs fastened to a pouch. A small stone was placed in the pouch, and the slinger whirled the whole affair around to build up velocity before letting go of one of the cord ends to release the pro- jectile. While considerable velocity could be imparted to a projectile in this way, the geom- etry of the scheme dictated that the release be timed with uncanny precision to achieve even rudimentary accuracy. The sling vanished as a

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weapon of war in the Old World by the end of the classical period.

The Sword

As a serious military implement, the sword had to await the development of iron forging, and the first true swords date from about 1200 BCE. Swords in antiquity and classical times tended to be relatively short, at first because they were made of bronze and later because they were rarely called upon to penetrate iron armor. The blade of the classic Roman stab- bing sword, the gladius, was only some two feet (.6 m) long, though in the twilight years of the empire the gladius gave way to the spatha, the long slashing sword of the barbarians.

The Bow

In its most basic form, the bow consisted of a stave of wood slightly bent by the ten- sion of a bowstring connecting its two ends. The total amount of potential energy that an archer could store in a bow was a function of the bow's length. The longer the arms of the bow, the more kinetic energy imparted to the string and arrow. However long bows had lower velocity, while shorter bows compensated for less stored energy with higher velocity.

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Neolithic hunters used simple bows as depicted in cave paintings of 30,000 BCE and earlier. The first improvement was the reflex bow, a bow that was curved forward, or reflexively, near its center so that the string lay close against the grip before the bow was drawn. The next major improvement was the composite recurved bow. The composite bow's resistance to bending was increased by rein- forcing the rear, or belly, of the bow with horn; its speed and power in recoil were increased by overlaying the front of the bow with sinew, usually applied under tension. They acquired the name recurved since the outer arms of the bow curved away from the archer when the bow was strung. This bow was used as early as 3000 BCE.

A prime advantage of the composite bow was that it could be engineered to essentially any desired strength.

Arrows

Arrow design was probably the first area of military technology in which the cost of mak- ing them was important. As a consequence, the materials used for arrowheads tended to be a step behind those used for other offensive technologies. Arrowheads of flint and obsid- ian, knapped to remarkably uniform standards,

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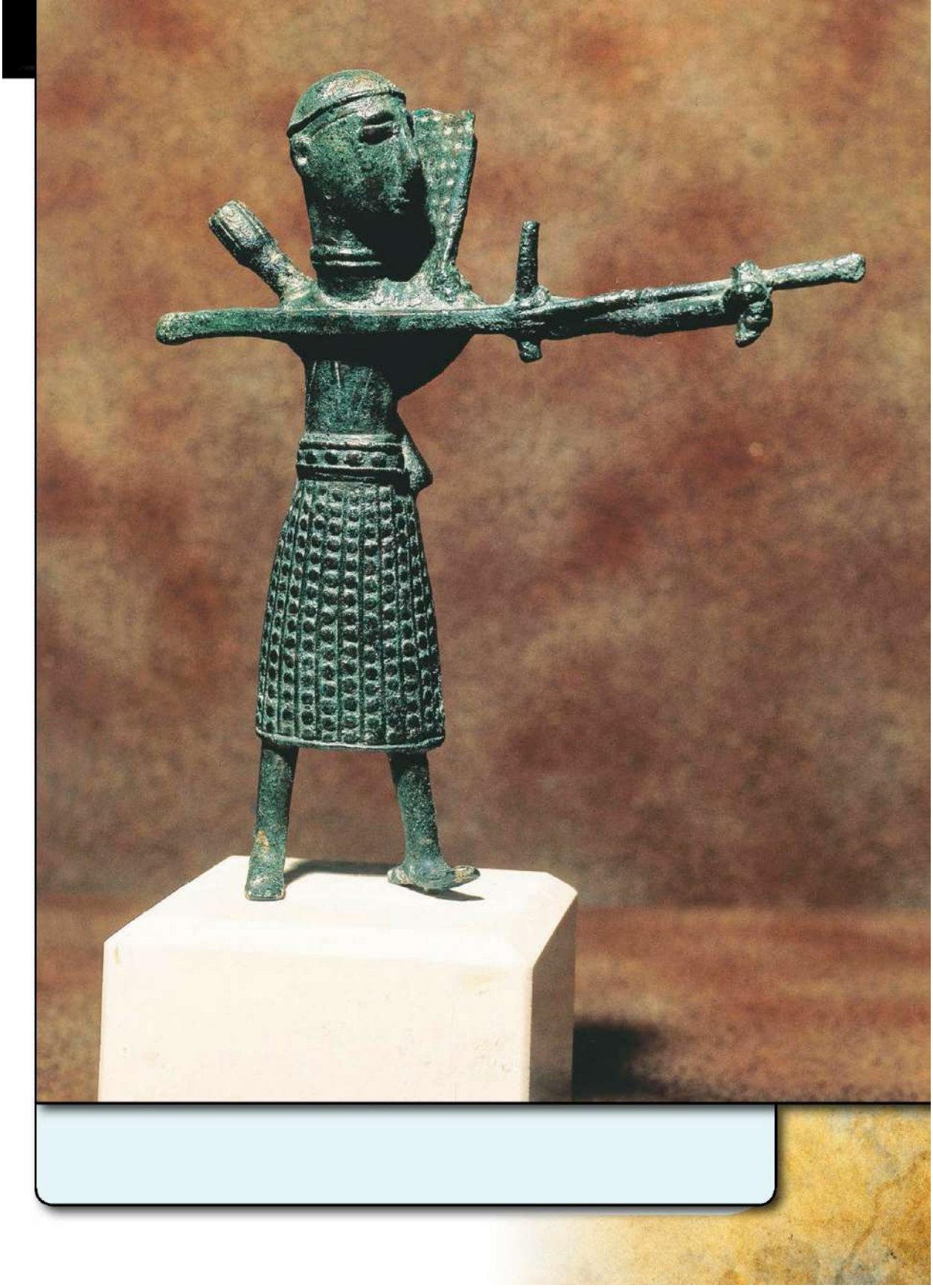
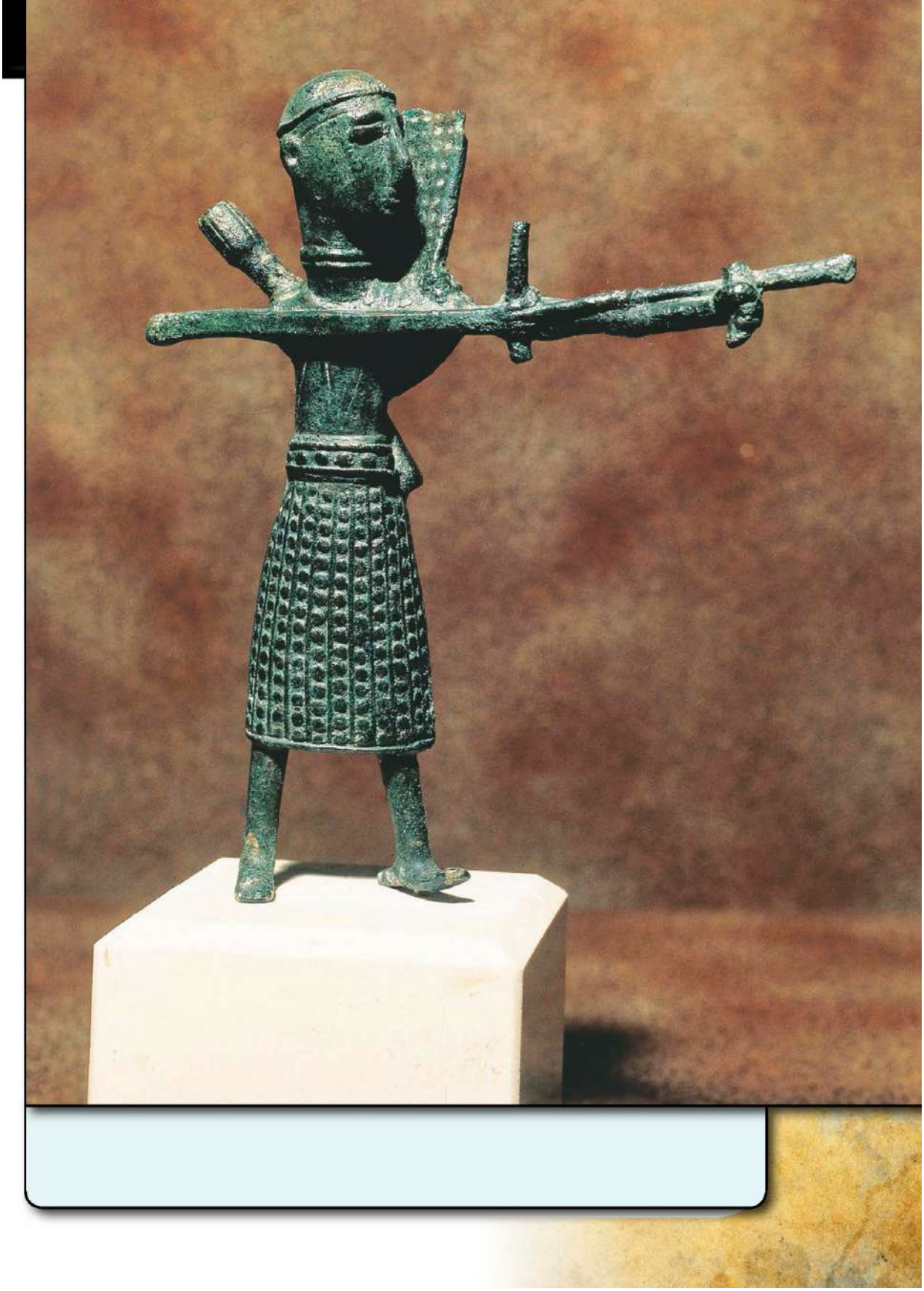


Bronze statue of an archer from the Sardinia region of Italy



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Mechanical Artillery

Mechanical artillery of classical times was of two types: tension and torsion. In the first, energy to drive the projectile was provided by the tension of a drawn bow; in the other, it was provided by torsional energy stored in bundles of twisted fibers.

The earliest of the Greek engines was the gastrophetes, or "belly shooter." In effect a large crossbow, it received its name because the user braced the stock against his belly to draw the weapon. By the middle of the 3rd cen- tury BCE, the bow had been replaced by rigid wooden arms constrained in a wooden box and drawn against the force of tightly twisted bundles of hair or sinew. Such catapults could throw a javelin as far as 800 yards (700 m). The same basic principle was applied to large stone-throwing engines.

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FORTIFICATION

Fortifications in antiquity were designed primarily to defeat attempts at escalade, though cover was provided for archers and javelin throwers along the ramparts and for fire from flanking towers. Roman fortresses of the 2nd century CE, tended to have square or rectangular outlines and were situated along major communication routes. By the late 3rd century, their walls had become thicker and had flank- ing towers strengthened to support mechanical artillery. The number of gates was reduced, and the ditches were dug wider. By the late 4th and 5th centuries, Roman fortresses were being built on easily defensible ground with irregu- lar outlines that conformed to the topography; clearly, passive defense had become the domi- nant design consideration.

Early field fortifications also used topography to their advantage. The Greeks aimed to secure an advantage by standing on higher ground so that the enemy was forced to attack uphill. The Romans were especially adept at

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towers that remain a wonder to modern engineers. So large was one siege tower used by Macedonians in an attack on Rhodes that 3,400 men were required to move it up to the city walls. Another 1,000 men were needed to wield a battering ram 180 feet (55 m) long. The Romans constructed huge siege towers, one of which Caesar mentions as being 150 feet (46 m) high. The lower stories housed the bat- tering ram, which had either a pointed head for breaching or a ramlike head for battering. Archers in the upper stories shot arrows to drive the defenders from their ramparts. From the top of the tower, a hinged bridge might be lowered to serve a storming party. To guard the attackers against enemy missiles, the Romans used great wicker or wooden shields, called mantelets, which were sometimes mounted on wheels. In some cases the attackers might approach the fortress under the protection of wooden galleries.

LAND TRANSPORTATION

In antiquity and classical times the transportation technology of land warfare largely amounted to man's own powers of locomotion. The horse was an economically inefficient animal, consuming large quantities of food. Of more importance, keeping and breeding

towers that remain a wonder to modern engineers. So large was one siege tower used by Macedonians in an attack on Rhodes that 3,400 men were required to move it up to the city walls. Another 1,000 men were needed to wield a battering ram 180 feet (55 m) long. The Romans constructed huge siege towers, one of which Caesar mentions as being 150 feet (46 m) high. The lower stories housed the bat- tering ram, which had either a pointed head for breaching or a ramlike head for battering. Archers in the upper stories shot arrows to drive the defenders from their ramparts. From the top of the tower, a hinged bridge might be lowered to serve a storming party. To guard the attackers against enemy missiles, the Romans used great wicker or wooden shields, called mantelets, which were sometimes mounted on wheels. In some cases the attackers might approach the fortress under the protection of wooden galleries.

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horses was labor-intensive and costly. Mules and donkeys fitted with carrying baskets, or panniers, balanced in pairs across the back, were the most common pack or dray animals. The ox, the heavy-duty dray animal of the Mediterranean world, was used for military purposes when heavy loads were involved and speed was not critical.

The horse was restricted to a subsidiary role in warfare from the eclipse of the chariot in the middle of the 2nd millennium BCE until the rise of the horse archer in the 4th century CE. Greek vase paintings from the 7th century BCE depict tall, apparently powerful horses with long, slender legs, implying speed. Later Mongolian steppe ponies, though tough and tractable, were probably considerably smaller.

The war elephant was first used in India and was known to the Persians by the 4th cen- tury BCE. Though they accomplished little subsequently, their presence in Hannibal's army during its transit of the Alps into Italy in 218 BCE underscored their perceived utility. The elephant's tactical importance apparently stemmed in large part from its willingness to charge both men and horses and from the panic that it inspired in horses.

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The chariot was the earliest means of transportation in combat. The earliest known chariots, shown in Sumerian depictions from

about 2500 BCE, were four-wheeled carts with solid wooden wheels drawn by a team of four donkeys or wild asses. They were no doubt heavy and cumbersome; lacking a pivoting front axle, they would have skidded through turns.

Around 1600 BCE Iranian tribes introduced the war-horse with the light two-wheeled char- iot. The Hyksos apparently introduced the chariot into Egypt shortly thereafter, by which time it was a mature technology. By the middle of the 2nd millennium BCE, Egyptian, Hittite, and Palestinian chariots were extraordinarily light and flexible vehicles. Light war chariots were drawn by either two or three horses, which were harnessed by means of chest girths secured by one or two poles and a yoke.

The decline of the chariot by the end of the 2nd millennium BCE was probably related to the spread of iron weaponry, but it was surely related also to the breeding of horses with suf- ficient strength and stamina to carry an armed man. Chariots lingered in areas of slower tech- nological advance, but in the classical world they were retained mainly for ceremonial functions.

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Conclusion

Humankind continues to manipulate the environment and create new technology to reach its collective needs more efficiently. It is impossible to pick one technology that provided the greatest impact on the evolu- tion of humans as each inevitably follows and builds off another. From the use of rocks to arrowheads, humans created ways to provide more meat and then controlled fire to cook it, thusmakingtheproceeds of the kill last longer. Farming and agricultural techniques ended the nomadic lifestyle for many and created towns and cities. Towns and cities begat a new social structure that required architectural advances and later military and defensive ones.

In Europe, the fall of the Romans would eventually lead to the Medieval and Renaissance periods. The former began in the 5th century CE and would continue until the 15th century. These eras brought their own powerful inno- vations, many of which were improvements or reworkings of Greek and Roman creations, such as the improved windmill and watermill. The 11th and 12th centuries would also her- ald the use of mills to harness tidal power and the advent of mechanical clocks. Like the all- important wheels that provided a new form of conveyance, the march of technology contin- ues ever forward.

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Glossary

amphitheaters Large buildings with curved row seating that rise around a space where games or plays are held.

barbs Sharp projections that extend backward, preventing them from being easily extracted.

breaching Making a hole or opening in something such as a wall or fortification.

campaign Coordinated military operation during war.

cire perdue A process used in metal casting where a wax model surrounded by clay is heated until it drains out of small holes and is then replaced by molten metal.

crucible The vessel in which metals are heated to very high temperatures or melted.

cuneiform A form of writing used in parts of the ancient Middle East.

distilling A process by which a liquid is heated until it becomes gas and then cooled again to make alcohol.

fermenting A process by which food goes through a chemical change to make alcohol.

forged Reshaping of iron by heating it.

hinterland A region that is remote from urban areas.

mail Body armor made of metal links and plates.

metallurgy The study of metals, specifically

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Neolithic The latest period of the Stone Age, characterized by polished stone implements.

Paleolithic A period during the early Stone Age when people made rough tools and weapons from stone.

redoubt A small building or area that provides protection to soldiers under attack.

sheaves Stalks and grain that are tied together after being cut.

topography The features of an area of land, such as mountains, plains, and rivers.

ziggurat Ancient Mesopotamian temple tower in the shape of a pyramid with outside staircases and a shrine at the top.

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For More Information

American Museum of Natural History
Central Park West at 79th Street
New York, NY 10024-5192
(212) 769-5100
Website: http://www.amnh.org
The American Museum of Natural History boasts a wide selection of artifacts from the ancient world.

Archaeological Institute of America
656 Beacon Street, 6th Floor
Boston, MA 02215-2006
(617) 353-9361
Website: http://www.archaeological.org
The institute is devoted to the field of archaeology. The group organizes activities to promote archaeological inquiry and an appreciation of diverse cultures.

The British Museum
Great Russell Street
London WC1B DG
England
Website: http://www.ancientcivilizations.co.uk/home_set.html
This museum provides online access to an ancient civilizations site that allows users to look at models and objects from the museum's extensive collection.

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The California Museum of Ancient Art
P.O. Box 10515
Beverly Hills, CA 90213
(818) 762-5500
The museum includes art and artifacts from the 3rd and 2nd millennia BCE. Its collection includes pieces from ancient Egypt, Mesopotamia, and the Holy Land.

Canadian Museum of History
100 Laurier Street
Gatineau, QB K1A 0M8
Canada
(800) 555-5621
Website: http://www.historymuseum.ca
This museum focuses on Canadian and world history and includes resources for those studying archaeology, ethnology, and cultural studies. The museum has a large collection of artifacts from the ancient world.

Metropolitan Museum of Art
1000 5th Avenue
New York, NY 10028
(212) 535-7710
Website: http://www.metmuseum.org
This museum has a large collection of items from the ancient world including artifacts from ancient Egypt and examples of Greco-Roman art, technology, and weaponry.

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For Further Reading

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